Improvements to the Standard Forest Products Trade Model: Illegal Logging

by

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ABSTRACT

This dissertation describes three improvements to the standard forest products trade model. The standard model typically contains multiple regions, multiple products, multiple manufacturing processes, price sensitive supply, price sensitive demand and transportation costs between regions. The models are used to predict sectoral economic activity and the trade of products among countries while contributing to policy creation, implementation and evaluation. The standard model has remained substantially unchanged since it was introduced in the early 1980s.

This dissertation is organized into four manuscripts. The first and second manuscripts introduce structural improvements to the standard model. The first manuscript suggests replacing the standard manufacturing cost component with a theoretically coherent cost component based on variable marginal costs. The second manuscript suggests replacing the idiosyncratic use of trade inertia with the use of Armington elasticities. The third and fourth manuscripts lead to content improvements in the modeling of illegal logging. The third manuscript presents a background analysis that explores the causal links between a country's development and corruption. The fourth and final manuscript utilizes the results of the three previous manuscripts in calibrating a revised trade model with special reference to illegal logging in Indonesia and its trade with China. This revised trade model incorporates the variable cost manufacturing component from the first manuscript, Armington elasticities from the second manuscript and predictions of corruption from the third manuscript.

The suggested improvements outlined in this dissertation, to the standard forest products trade model, will result in more accurate estimates of sectoral activity and trade. The improvement in estimates could lead to better policy creation, implementation and evaluation.

PREFACE

The research reported in this thesis, including: 1) the identification and design of the research, 2) the performance of the research, and 3) the analysis of the research was conducted by the author, Steven Northway. The thesis includes four manuscripts. Gary Bull assisted in preparing and editing the manuscripts.

A version of Chapter 2 is being submitted for publication. Northway, S. and G.Q. Bull. Agriculture and Forest Sector Partial Equilibrium Models: Processing Components.

A version of Chapter 3 is being submitted for publication. Northway, S., J.G. Bull and G.Q. Bull. Armington Elasticity and Trade Inertia Constraints in Forest Products Trade Models.

A version of Chapter 4 has been accepted for publication. Northway, S. and G.Q. Bull. 2011. Are a Country's Corruption and Development Related? : A Longitudinal Cross-Lagged Structural Equation Model Analysis. *Journal of the Academy of Business and Economics.*

A version of Chapter 5 will be submitted for publication. Northway, S. and G.Q. Bull. Illegal Logging in Forest Sector Trade Models: The Inclusion of Corruption.

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1 INTRODUCTION

Trade models are used to assist in policy creation, implementation and evaluation (Tongeren et al. 2000). Broadly speaking, trade models are either General Equilibrium Models (GEM) or Partial Equilibrium Models (PEM). GEMs represent comprehensive sets of markets and goods for the global economy; and in doing so deal with global macroeconomic conditions. PEMs, in contrast, only represent a subset of the global markets and goods, allowing them to deal with a particular economic sector in much more detail, but take global macroeconomic conditions as exogenous.

GEMs contain, necessarily, a very simple representation of the forest sector. For instance, the Global Trade Assessment Model, only represented 'logging and silviculture' [1], 'lumber and wood' and 'pulp and paper' sub-sectors and 113 regions in its analysis (Hertel 1997 and Liu et al. 2005). An other GEM included 13 forest related sub-sectors but only 1 region (Resosudarmo and Yusuf 2006). In both models, only one kind of 'log' was supplied to the modeling process and this coarse aggregation of thousands of tree species and varying log qualities is problematic, given the variety of products produced around the world. In my view, this level of aggregation prevents the model from being useful to test policy initiatives specifically directed at the forest sector.

PEMs have been used extensively in the forest sector. They have been used as the basis for evaluating: comprehensive global forest sector analysis (Kallio 1987), the effect of accelerated

[1] Labeled 'forestry' in the original.

tariff liberalization on the environment (Brooks 2003), the effects of tariff liberalization (Buongiorno et al. 2003), the economic impact of accelerating growth in European forests (Solberg et al. 2003), the effect of an insect outbreak on the Canada-Japan trade in logs (Gaston and Marinescu 2006), and the implications of China's increasing demand for forest products on Asia-Pacific trade (Northway and Bull 2006).

Forest sector PEMs have also been used to examine more specific trade policy issues such as the impacts of illegal logging on trading behaviour. They have been used to evaluate: the impact of illegal logging on the United State's forest products industry (Seneca 2004), the impacts of bilateral trade agreements on the trade of illegal forest products between Indonesia and China (Northway and Bull 2009), the impact of illegal logging on the New Zealand forest products sector (Turner et al. 2007), the effect of a slow reduction of illegal logging on the global forest sector (Li et al. 2008), and the impact of European Union policy measures to curb illegal logging on global trade (Moiseyev et al. 2010). The application of the PEMs at the more generic or more specific levels of analysis all use a 'standard' approach to both formulating forest sector PEMs and applying them to trade policy issues. The next section will describe, in some detail, these standard approaches.

1.1 The Standard Forest Product Trade Model

In the early 1980s, forest sector PEM modeling originated at IIASA with the development of the Global Trade Model (GTM) (Dykstra and Kallio 1987). In the 1990s, CINTRAFOR at the University of Washington used the structure of the IIASA GTM model for the development of the CINTRAFOR Global Trade Model (CGTM) (Cardellichio and Adams 1990). Another

research group used the GTM as a starting point to develop the Global Forest Products Model (GFPM) (Buongiorno et al. 2003). These three models also influenced the development of other forest sector trade models including the European Forestry Institute Global Trade Model (EFI-GTM) (Kallio et al. 2004), the FORINTEK Global Trade Model (FGTM) (Gaston and Marinescu 2006) and finally, the International Forest and Forest Products model (IFFP) (Northway and Bull 2006). A standard forest product trade model structure developed as the initial proposed structure has been largely adopted by subsequent modelers.

Equation [1.1] illustrates the material balance constraint found in the standard model:

$$S_{ik} + \sum_{j} T_{jik} + \sum_{n} Y_{ikn} \geq D_{ik} + \sum_{j} T_{ijk} + \sum_{n} a_{ikn} * Y_{ikn} \qquad \forall\, i, k \qquad [1.1]$$

where i,j=regions, k=products, n=processes, S=supply, T=trade, Y=manufacturing process, D=demand, and a=conversion efficiency. This constraint ensures that, for every product in every country, the domestic supply, plus the imports, plus any amount generated by domestic manufacturing is sufficient to meet consumer demand, plus exports, plus any amount consumed in domestic manufacturing.

Using Samuelson's (1952) observation that the 'usual' trade problem could be solved by expressing it as an optimization problem, the standard forest sector models are solved by minimizing the expression in [1.2], subject to [1.1]:

$$\sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})\ \delta D_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik})\ \delta S_{ik}$$

$$- \sum_i \sum_j \sum_k c_{ijk} * T_{ijk} - \sum_i \sum_k \sum_n m_{ikn} * Y_{ikn} \qquad [1.2]$$

where P=price, c=transport cost and m=manufacturing cost. Note that the manufacturing costs are fixed and represent constant marginal costs.

Several additional constraints are required to ensure good model behavior. Equation [1.3] is the standard way to limit manufacturing capacity; and equations [1.4] and [1.5] represent a set of constraints bounding trade.

$$Y_{ikn} \leq Y_{ikn}^U \qquad \forall\ i,k,n \qquad [1.3]$$

$$T_{ijk} \leq T_{ijk}^U \qquad \forall\ i,j,k \qquad [1.4]$$

$$T_{ijk} \geq T_{ijk}^L \qquad \forall\ i,j,k \qquad [1.5]$$

where Y^U=capacity, T^U=upper limit of trade and T^L=lower limit of trade. The absolute limits to trade in [1.4] and [1.5] are often labeled as 'trade inertia' constraints. This completes the specification of the standard forest products trade model.

1.2 Standard Method to Represent *Status Quo* Levels of Illegal Logging in Forest Trade Models

By its very nature, statistics on illegal activities are difficult to find; therefore, one has to use indirect methods to estimate the activities. One method is to evaluate the discrepancies in

government-collected trade statistics to estimate illegal sources of forest products. While there are other explanations for the discrepancies, such as recording errors and language problems, researchers in the field still feel that illegal activities are a significant source of discrepancies in the statistics (Goetzl 2005).

A second method is to combine illegal logging estimates with other relevant data. For example, a country-level wood balance may show the reported timber harvest, combined with imports and exports, as insufficient to support the level of manufacturing reported. In this case, the unexplained deficit of reported logs could be inferred as coming from illegal logging. Johnson (2003) and Seneca (2004) made use of this method to make comprehensive-global estimates.

A third method was employed by Contreras-Hermosilla et al. (2007) in which he compiled global estimates by adding up country specific estimates that had been developed through a variety of published sources. Table 1.1 presents a representative set of estimates (Contreras-Hermosilla et al. 2007).

Table 1.1 Estimates of illegal logging (% of total)

Africa		Asia		Europe and North Asia		Latin America	
Benin	80	Cambodia	90	Albania	90	Bolivia	80
Cameroon	50	Indonesia	88	Azerbaijan	90	Brazil	80
Ghana	66	Malaysia	33	Bulgaria	45	Colombia	42
Mozambique	60	Myanmar	80	Georgia	85	Costa Rica	25
				Russia	30	Ecuador	70
						Honduras(HW)	80
						Honduras(SW)	40
						Nicaragua	45

(Source: Contreras-Hermosilla et al. 2007)

A consistent message from authors of all these three methods is that statistics on illegal logging are difficult to find, somewhat subjective and only available for single points in time.

In the research conducted on modeling illegal logging, a nearly consistent method has been used to represent *status quo* illegal logging in trade modeling studies (Seneca 2004; Turner et al. 2007; Li et al. 2008; Northway and Bull 2009; Moiseyev et al. 2010). In all those studies mentioned above, with the exception of the Northway and Bull (2009) study, the flow of illegal logs through trade and manufacturing is calculated *post hoc* as proportional to the fraction of illegal logging assumed to be represented in the region's supply curve. In each case, however, the current estimate of illegal logging (as a percent of total logging) was assumed to remain static through the length of the study. This assumption of a static fraction for illegal logging belies the accepted relationship between illegal logging and corruption (Seneca 2004), which in its turn is tied to development (Mo 2001).

1.3 Research Goals

In contrast to the standard model for forest products trade models, I argue in this thesis, that three specific improvements could result in a more economically coherent and accurate estimates of sectoral activity and trade. The suggested improvements are: 1) an improvement on the constant marginal costs curves used in the manufacturing sector, 2) an improvement on the trade inertia constraints used in the trade component of trade models, and 3) an improvement on the *status quo* illegal logging rates.

1.4 Dissertation Structure

The structure of this dissertation follows the guidelines for manuscript-based dissertations. Following this introduction are four manuscripts that form the main body of this dissertation.

In the first manuscript (Chapter 2: *Agriculture and Forest Sector Partial Equilibrium Models: Processing Components*), I focus on the processing component of forest and agriculture sector trade models. In the forest sector, the processing component is nearly universally represented by the sum of an exogenous average per unit cost plus the costs of endogenous inputs; the former costs are, in effect, constant marginal costs of production. I illustrate a method to construct a partial equilibrium model using variable marginal costs for production and explicitly includes the cost of endogenous inputs. Through a forest sector model (GFPM), I evaluate the implications of using constant and variable marginal costs to represent the processing component. I demonstrate that more coherent processing components can be easily included in existing partial equilibrium models and that utilizing variable marginal costs in the processing components improves model behavior. I conclude that the constant marginal cost components in forest sector models should be replaced with a variable marginal cost.

In the second manuscript (Chapter 3: *Armington Elasticity and Trade Inertia Constraints in Forest Products Trade Models*), I test the merits of using trade inertia and Armington elasticities in forest products trade models. One corollary of the basic assumptions underlying all resource trade models is that *cross hauling* will not occur; however, all situations the models represent seem to violate this assumption. Modelers are typically then required to make adjustments by the use of Armington elasticity, or in the case of forest product trade models, the use of trade

inertia. These two approaches are fundamentally different in how they affect substitution between import and domestic products. The purpose of this chapter, then, is to: 1) examine the implications of using trade inertia constraints in forest products trade model, 2) appraise the feasibility of using Armington elasticity to replace trade inertia in a standard forest product trade model (GFPM), and 3) through the use of a standard forest products trade model (GFPM) evaluate the hypothesis that Armington elasticity is more responsive than trade inertia to trading cost shocks. I conclude that: 1) despite its implications, the use of trade inertia or Armington elasticity in forest products trade modeling will continue given the data limitation; 2) the trade inertia could be replaced by a linear approximation to Armington elasticity; and 3) Armington elasticity is more responsive than trade inertia to trading costs shocks.

In the third manuscript (Chapter 4: *Are a Country's Corruption and Development Related? : A Longitudinal Cross-Lagged Structural Equation Model Analysis*), I examine the empirical evidence for cause-effect linkages between growth and corruption utilizing a cross-lagged structural equation model. The official policy of aid agencies and development banks has been to encourage a reduction in corruption as a step towards promoting economic development and poverty alleviation. I conclude that there is an overall tendency for countries to regress to a *normal* level of corruption for their level of economic development. Further, within this tendency, increased economic development leads to a reduction in corruption, but a reduction in corruption does not, in itself, lead to an increase in economic development.

In the fourth manuscript (Chapter 5: *Illegal Logging in Forest Sector Trade Models: The Inclusion of Corruption*), I incorporate the results of the first three manuscripts into a test of a

better way to represent illegal logging under the *status quo.* Global trade models are used to predict the impact of illegal logging on the forest sector and a key variable is the prevalence of future illegal logging. The usual assumption is that illegal logging remains a constant proportion of a country's total production; this assumption is then used to test the impact of policy instruments designed to eliminate illegal logging. I wish to challenge this assumption and I use the IFFP to explore a method to represent illegal logging as varying with the general level of corruption in a country. I conclude that the use of this dynamic approach improves the impact estimates of eliminating illegal logging.

In the final chapter of this dissertation I summarize the main results and establish linkages between the four manuscripts. I also identify limitations of the research presented in this dissertation and discuss directions for future research in forest products trade modeling that could lead to better policy creation, implementation and evaluation.

2 AGRICULTURE AND FOREST SECTOR PARTIAL EQUILIBRIUM MODELS: PROCESSING COMPONENTS[2]

2.1 Introduction

Partial equilibrium models (PEMs) are used to predict sectoral economic activity and the trade of products among countries (Roningen 1997). As opposed to General Equilibrium Models that deal with the global economy as a whole, PEMs typically represent a particular sector of the economy, such as forestry or agriculture, for each of several regions or countries. The intent of modeling exercises using PEMs is to contribute to policy creation, implementation and evaluation (Tongeren et al. 2001).

In the agriculture sector, PEMs have seen widespread application in recent decades. In 1986, the Uruguay Round of trade talks stimulated a renewed effort in modeling the international agriculture sector (Roningen 1997). The Organization for Economic Co-operation and Development (OECD) developed an agriculture sector PEM (AGLINK) for member countries (OECD 1987). The International Institute of Applied System Analysis (IIASA) redirected their existing PEM agriculture model from problems of food distribution to trade issues (Parikh et al. 1988). The United States Department of Agriculture (USDA) developed the Static World Policy Simulation Model (SWOPSIM) (Roningen and Dixit 1990). In 1994, at the end of the Uruguay

[2] A version of this chapter is being submitted for publication. Northway, S. and G.Q. Bull. Agriculture and Forest Sector Partial Equilibrium Models: Processing Components.

Round, there were several PEM based estimates of agriculture policy impacts. At the end of the 1990s there were at least 8 active PEM agriculture trade models (Tongeren et al. 2000).

Model development has continued, notably with ESIM, having its roots in the USDA as a SuperCalc application, which later branched into a USDA EXCEL application and then branched into a GAMS framework by the DG AGRI (Banse et al. 2004). It is this later version of the model that we will refer to as ESIM. Finally, WATSIM has seen continued development through a partnership between the EU and the University of Bonn (Khun 2003).

In the forest sector, PEMs did not have the galvanizing force of a multilateral trade negotiation to drive their development. Nonetheless, PEM development did begin in the 1980s and by the end of 2009, there were at least 5 forest sector PEM models developed (Northway et al. 2011). In the early 1980s, forest sector PEM modeling originated at IIASA with the development of the Global Trade Model (GTM) (Dykstra and Kallio 1987); it was the first comprehensive global forest sector analysis modeling effort (Kallio et al. 1987). Later, the structure of the IIASA GTM model was adapted for the CINTRAFOR Global Trade Model (CGTM) (Cardellichio and Adams 1990); it is still maintained by the Center for International Trade in Forest Products (CINTRAFOR) at the University of Washington. CGTM has been used in many trade studies, including an examination of the effect of accelerated tariff liberalization on the environment (Brooks 2003). Another modeling effort led to the GTM being used as a starting point in developing the Global Forest Products Model (GFPM) (Buongiorno et al. 2003); one of its applications was in studies on tariff liberalization (Buongiorno et al. 2003).

These earlier models also influenced the development of other forest sector trade models. The European Forestry Institute Global Trade Model (EFI-GTM) (Kallio et al. 2004) was used to evaluate the economic impact of accelerating growth in European forests (Solberg et al. 2003). The FORINTEK Global Trade Model (FGTM) has been used to look at the effect of an insect outbreak on the Canada-Japan trade in logs (Gaston and Marinescu 2006). Finally, the International Forest and Forest Products model (IFFP) has been used to explored the implications of China's increasing demand for forest products on Asia-Pacific trade (Northway and Bull 2006).

PEMs have four major components: supply, demand, processing and inter-regional trade (Roningen 1997). PEMs deal with up to three kinds of products: 1) primary products (such as seed in agriculture and logs in forestry), 2) intermediate products (such as pulp in forestry), and 3) final products (such as seed oil and cake in agriculture and paper in forestry). The supply component is a set of econometric supply curves relating quantity to price for the primary sectoral products. The demand component is a set of econometric demand curves relating quantity to price for final sectoral products; this might include primary sectoral products. The processing component is made up of technical coefficients relating the quantity of input products to the quantity of output products and processing cost curves relating processed quantity to cost. In the processing component, input products may be primary products (e.g. agricultural seeds or forestry logs) or intermediate products (e.g. forestry pulp), and output products may be intermediate products or final products (e.g. forestry pulp or agricultural seed oil and cakes and forestry paper). Finally, the inter-regional trade component has trade costs for products such as the primary products, intermediate products or final products. With these components identified

and the relevant data collected or estimated, the PEM is capable of predicting global and regional level sectoral activity and trade.

The agriculture and forest sectors have quite different structures and this is reflected in the PEMs formulation. For example, early agriculture PEMs did not include a processing component and we surmise this is because the trade and manufacturing of processed agricultural goods was not important in understanding the sector. In contrast, even the earliest forest sector PEMs contained a processing component, as the trade and manufacture of processed forest goods is an important aspect of the sector.

Several important agriculture PEMs now include a processing component, but it seems they have taken a different tack than the traditional forest sector PEMs. We felt these differences were important and warranted closer scrutiny.

In this context, the purpose of this paper is to:

1) Evaluate the processing components in a typical agriculture and forest sector PEM;
2) Develop coherent cost formulations for use in the processing components of agriculture and forest sector PEMs; and,
3) Demonstrate, in a typical forest sector model, the importance of an improved formulation.

2.2 Partial Equilibrium Models

2.2.1 Agriculture sector PEM

Some early agriculture PEMs represented some product prices or quantities as fixed (Heady and Srivistava, 1975). However, most represented the supply and demand components as curves relating price to quantity; expressing and solving the relationships through a set of simultaneous equations.

The processed products component is only explicitly incorporated into two of eight active PEMS at the end of the 1990s (Tongeren et al. 2000). They were: ESIM (Banse et al. 2004) and WATSIM (Kuhn 2003). To demonstrate how these two PEMs incorporate processing we present, equations [2.1] to [2.12] as a stylized agriculture PEM. These equations represent an undetermined number of regions, and by way of illustration, one primary product (seed) and two secondary products (oil and cake). All products are traded and they are consumed through demand curves. For clarity, the equations are expanded to explicitly include all the products represented in each region.

Equations [2.1]-[2.5] ensure a materials balance:

$$S_{r,seed} = D_{r,seed} + I\_in_{r,s2o,seed} + I\_in_{r,s2c,seed} + EXP_{r,seed} - IMP_{r,seed} \qquad \forall\, r \qquad [2.1]$$

$$I\_in_{r,s2o,seed} = \tau_{r,s2o,oil} I\_out_{r,s2o,oil} \qquad \forall\, r \qquad [2.2]$$

$$I\_in_{r,s2c,seed} = \tau_{r,s2c,cake} I\_out_{r,s2c,cake} \qquad \forall\, r \qquad [2.3]$$

$$D_{r,oil} = I\_out_{r,s2o,oil} - EXP_{r,oil} + IMP_{r,oil} \qquad \forall\, r \qquad [2.4]$$

$$D_{r,cake} = I\_out_{r,s2c,cake} - EXP_{r,cake} + IMP_{r,cake} \qquad \forall\, r \qquad [2.5]$$

where r = region, seed = a seed product, oil = seed derived oil product, cake = a seed derived cake product, s2o = a seed to oil industrial process, s2c = a seed to cake industrial process, *S* = quantity supplied, *D* = quantity demanded, *I_in* = quantity input to an industrial process, *I_out* = quantity output from an industrial process, τ = conversion efficiency in an industrial process, *EXP* = quantity of a product exported, *IMP* = quantity of a product imported.

Equation [2.1] ensures, within a region, the domestic supply of seeds plus any imported seed must either be exported, utilized in demand for consumption of seed or as input into industrial processes to result in oil or cake. Equations [2.2] and [2.3] ensure that the output of oil and cake from the processed seed is limited to the conversion efficiency of the processes. Equations [2.4] and [2.5] ensure that consumption plus any exports of oil and cake is met by the output of the domestic industrial process plus imports.

Equations [2.6] to [2.9] represent the price-quantity relationships for supply and demand.

$$S_{r,seed} = c^{S}_{r,seed} P_{r,seed}^{\varepsilon^{S}_{r,seed,seed}} \qquad \forall r \qquad [2.6]$$

$$D_{r,seed} = c^{D}_{r,seed} P_{r,seed}^{\varepsilon^{D}_{r,seed,seed}} \; P_{r,oil}^{\varepsilon^{D}_{r,seed,oil}} P_{r,cake}^{\varepsilon^{D}_{r,seed,cake}} \qquad \forall r \qquad [2.7]$$

$$D_{r,oil} = c^{D}_{r,oil} P_{r,oil}^{\varepsilon^{D}_{r,oil,oil}} \; P_{r,seed}^{\varepsilon^{D}_{r,oil,seed}} P_{r,cake}^{\varepsilon^{D}_{r,oil,cake}} \qquad \forall r \qquad [2.8]$$

$$D_{r,cake} = c^{D}_{r,cake} P^{\varepsilon^{D}_{r,cake,cake}}_{r,cake} \; P^{\varepsilon^{D}_{r,cake,seed}}_{r,seed} P^{\varepsilon^{D}_{r,cake,oil}}_{r,oil} \qquad \forall r \qquad [2.9]$$

where P = price, c = constant and ε = elasticity.

Equation [2.6] relates quantity of seed supplied by a region with the local price through a constant and an own-price elasticity. Equations [2.7] through [2.9] relate the regional demand of seed, oil and cake for direct consumption with their local prices through a constant, cross-price elasticities and an own-price elasticity.

Equations [2.10] and [2.11] represent the price-quantity relationships for processing.

$$P_{r,oil} = c^{I}_{r,oil} I\_out^{\varepsilon^{I}_{r,oil,oil}}_{r,s2o,oil} \; P^{\varepsilon^{I}_{r,oil,seed}}_{r,seed} P^{\varepsilon^{I}_{r,oil,cake}}_{r,cake} \qquad \forall r \qquad [2.10]$$

$$P_{r,cake} = c^{I}_{r,cake} I\_out^{\varepsilon^{I}_{r,cake,cake}}_{r,s2c,cake} \; P^{\varepsilon^{I}_{r,cake,seed}}_{r,seed} P^{\varepsilon^{I}_{r,cake,oil}}_{r,oil} \qquad \forall r \qquad [2.11]$$

Equations [2.10] and [2.11] relate quantity of oil and cake produced through processing in a region with local conditions through a constant, cross-price elasticities and an own-quantity elasticity. A cross-elasticity is used to reflect the price effect of seed as an input product on the price of its resulting processed products: oil and cake rather than the more direct effect of an endogenous input cost.

Equation [2.12] enforces the equilibrium condition of a one-world price assumption as a way to 'close' the model through providing an equal number of equations for the number of unknown parameters to be estimated. Trade is allowed for all three products at no cost.

$$WP_{seed} = P_{r,seed}\ ;\ WP_{oil} = P_{r,oil}\ ;\ WP_{cake} = P_{r,cake} \qquad \forall r \qquad [2.12]$$

This agriculture trade model is now solved as a system of equations. Calibration is done by altering the constants (c) to approximate an equilibrium condition at the base year of the base scenario.

2.2.2 Forest sector PEM structure

The main forest sector PEMs share a very similar structure. GFPM, CGTM and EFI-GTM all have supply curves for primary products, demand curves for final products, constant per unit trading costs and constant per unit processing costs to process primary products into final products. The FGTM is more like the main agriculture models in not having a processing component. The IFFP is unique in having a quantity-price relationship for processing (Northway and Bull 2006). All of these models express and solve the PEM as a mathematical optimization problem.

Equations [2.13] to [2.24] represents a stylized forest sector PEM illustrating the structure of the processing component as found in the older and most widely used trade models (GFPM, CGTM, EFI-GTM). It represents an undetermined number of regions, one primary product (log) and two secondary products (lumber and panel). All products are traded. Logs are not consumed through a demand curve, they are only inputs for the processing of the lumber and panels. The lumber and panels are consumed through demand curves. For clarity, the equations are expanded to explicitly include all the products represented in each region.

As in agriculture sector PEMs, forest sector PEMs start with equations to ensure the materials balance. Equations [2.13]-[2.17] are analogous to the agriculture sector equations [2.1]-[2.5].

$$S_{r,log} = I\_in_{r,lumber} + I\_in_{r,panel} + EXP_{r,log} - IMP_{r,log} \qquad \forall\, r \qquad [2.13]$$

$$I\_in_{r,lumber} = \tau_{r,lumber} I\_out_{r,lumber} \qquad \forall\, r \qquad [2.14]$$

$$I\_in_{r,panel} = \tau_{r,panel} I\_out_{r,panel} \qquad \forall\, r \qquad [2.15]$$

$$D_{r,lumber} = I\_out_{r,lumber} - EXP_{r,lumber} + IMP_{r,lumber} \qquad \forall\, r \qquad [2.16]$$

$$D_{r,panel} = I\_out_{r,panel} - EXP_{r,panel} + IMP_{r,panel} \qquad \forall\, r \qquad [2.17]$$

Equation [2.13] ensures, within a region, the domestic supply of logs plus any imported logs must either be utilized as input into industrial processes to result in lumber or panel. Equations [2.14] and [2.15] ensure that the output of lumber and panel from the processed log is limited to the conversion efficiency of the processes. Equations [2.16] and [2.17] ensure that the demand for consumption plus any exports of lumber and panel is met by the output of the domestic industrial process or imports.

Using Samuelson's (1952) observation that the 'usual' trade problem could be solved by expressing it as an optimization problem, the main forest sector models are solved by minimizing the expression in equation [2.18] subject to equations [2.13] through [2.17]:

$$maximize\ Z =$$

$$-\int_0^{S_{r,log}} c^S_{r,log} P_{r,log}^{\varepsilon^S_{r,log,log}}\ \delta S_{r,log}$$

$$+\int_{0}^{D_{r,lumber}} c^{D}_{r,lumber} P_{r,lumber}^{\varepsilon^{D}_{r,lumber,lumber}} \ \delta D_{r,lumber}$$

$$+\int_{0}^{D_{r,panel}} c^{D}_{r,panel} P_{r,panel}^{\varepsilon^{D}_{r,panel}} \ \delta D_{r,panel}$$

$$-c^{I}_{r,lumber} I\_out_{r,lumber}$$

$$-c^{I}_{r,panel} I\_out_{r,panel} \qquad \forall\, r \qquad [2.18]$$

where the elements of equation [2.18] represent the log supplier's surplus, the lumber consumer's surplus, the panel consumer's surplus, the lumber processor's surplus and the panel processor's surplus.

The material balance plus the objective function is all that is needed to define the problem; it can then be solved through the method of Lagrangian multipliers (Cox and Chavas 2000), or through linear programming with a segmented linear approximation of the objective function (Northway and Bull 2006). Calibration is done by altering the constants (*c*) to approximate an equilibrium condition at the base year of the base scenario.

There is an equivalent system of equations problem ***implicit*** in this definition. Equations [2.19] to [2.21] represent the ***implicit*** price-quantity relationships for supply and demand.

$$S_{r,log} = c^{S}_{r,log} P_{r,log}^{\varepsilon^{S}_{r,log,log}} \qquad \forall r \qquad [2.19]$$

$$D_{r,lumber} = c^{D}_{r,lumber} P_{r,lumber}^{\varepsilon^{D}_{r,lumber,lumber}} \qquad \forall r \qquad [2.20]$$

$$D_{r,panel} = c^{D}_{r,panel} P^{\varepsilon^{D}_{r,panel,panel}}_{r,panel} \qquad \forall r \qquad [2.21]$$

Equation [2.19] relates quantity of logs supplied by a region with the local price through a constant and an own-price elasticity. Equations [2.20] and [2.21] relate the regional demand of lumber and panel for direct consumption with their local prices through a constant and an own-price elasticity. These price-quantity relationships differ from the common agriculture ones by not including cross-elasticities, though the elasticities are implied through the allocation of the logs to either lumber or panel.

Equations [2.22] and [2.23] represent the ***implicit*** price-quantity relationships for processing.

$$P_{r,lumber} = c^{I}_{r,lumber} + P_{r,log} * \tau_{r,lumber} \qquad \forall r \qquad [2.22]$$

$$P_{r,panel} = c^{I}_{r,panel} + P_{r,log} * \tau_{r,panel} \qquad \forall r \qquad [2.23]$$

Equations [2.22] and [2.23] relate quantity of lumber and panel produced through processing in a region with local conditions through a constant and the endogenous price of the necessary input of logs. Note that there is no elasticity based on the quantity of output, implying a constant marginal cost of production. Agriculture sector PEMs takes a different tack and we will discuss the implications of using a constant marginal cost later in the paper.

Equation [2.24] represents the ***implicit*** one-world price assumption inherent in the model. Trade is allowed for all three products at no cost.

$$WP_{log} = P_{r,log}\ ;\ WP_{lumber} = P_{r,lumber}\ ;\ WP_{panel} = P_{r,panel} \qquad \forall r \qquad [2.24]$$

In the general formulations of agriculture and forest PEMs, the most obvious differences come in their approach to the processing components. We felt these differences warranted closer scrutiny. Therefore, the next section will concentrate on the theoretical aspects of processing components: specifically: 1) the exclusion of direct costs for endogenous products in the processing component of typical agriculture sector PEMs, and 2) the use of constant marginal costs in the processing component of typical forest sector PEMs.

2.3 Theory

In this section we base our evaluation of agriculture and forest PEMs on theory (Tongeren et al. 2001). A key assumption of a PEM is that supply, demand and processing components represent a large number of rational agents trying to maximize their utility. The aggregate behavior of the suppliers results in an upward sloping supply curve; and the aggregate behavior of the consumers results in a downward sloping demand curve. Similarly, the aggregate behavior of the processors will result in an upward sloping process-supply curve.

Since we are focusing on processing, consider a particular process within a region. Assume there are a large number of processors operating in competitive markets, purchasing their input products and selling their output product. While the input products and output product are homogenous across processors, the processors differ in their production process. The cost of producing the output product will be made up of two elements: 1) the price of the input products, and 2) the costs associated with the process itself. Assuming the processors strive to maximize the difference between their selling price and production costs, the resulting aggregate output product-supply curve will be a marginal cost schedule, where the prices of the input products

equal their marginal value and the rest of the product price is made up of the marginal cost of processing one more unit of the output product by the marginal producer.

From this theoretical point of view we expect to see two elements making up a processor's cost calculation: 1) the cost due to endogenous inputs, and 2) a cost schedule for the remaining processing costs.

2.3.1 Agriculture sector

Typical agriculture PEMs (ESIM and WATSIM) do not include a direct cost factor for endogenous inputs in their processing sector component. While this does not necessarily result in unacceptable empirical results, it is theoretically more coherent to include the costs of endogenous inputs directly. This can be accomplished by altering the common agricultural cost model (equations [2.10] and [2.11]) to include the endogenously determined price of inputs as follows:

$$P_{r,oil} = c^{I}_{r,oil} I\_out^{\varepsilon^{I}_{r,oil,oil}}_{r,oil} \; P^{\varepsilon^{I}_{r,oil,seed}}_{r,seed} P^{\varepsilon^{I}_{r,oil,cake}}_{r,cake} + P_{r,oil}/\tau_{r,seed} \qquad \forall r \qquad [2.25]$$

$$P_{r,cake} = c^{I}_{r,cake} I\_out^{\varepsilon^{I}_{r,cake,cake}}_{r,cake} \; P^{\varepsilon^{I}_{r,cake,seed}}_{r,seed} P^{\varepsilon^{I}_{r,cake,oil}}_{r,oil} + P_{r,oil}/\tau_{r,cake} \qquad \forall r \qquad [2.26]$$

So we proposed to modify equations [2.10] and [2.11] and include the more direct effect of endogenous input costs in equations [2.25] and [2.26]. The quantity of oil and cake produced through processing in a region is represented by a constant, cross-price elasticities, and an own-quantity elasticity. However, we have expanded the equation and the last element includes the

more direct effect of endogenous input costs, making it more consistent with the theoretical argument presented above. This amended model is still solved using a system of equations and the calibration is still done by altering the constants (c) to approximate an equilibrium condition at the base year of the base scenario.

2.3.2 Forest sector

The typical forest sector PEMs (GFPM, CGTM, and EFI-GTM) do not include a variable marginal cost in their processing sector. While this is not theoretically untenable, it does lead to unstable model behaviour. We would expect unstable results as the manufacturing activity goes from one country to the next based on who can reach the export market. A country manufacturer has three options: it does not manufacture, it manufactures enough to fulfill domestic needs or it operates at 100% of capacity if it can reach export markets.

Amending the common forest sector cost model can be accomplished with the same techniques utilized in including the demand and supply components in the objective function [2.18]:

$$maximize\ Z =$$

$$-\int_{0}^{S_{r,log}} c_{r,log}^{S} P_{r,log}^{\varepsilon_{r,log,log}^{S}}\ \delta S_{r,log}$$

$$+\int_{0}^{D_{r,lumber}} c_{r,lumber}^{D} P_{r,lumber}^{\varepsilon_{r,lumber,lumber}^{D}}\ \delta D_{r,lumber}$$

$$+\int_{0}^{D_{r,panel}} c_{r,panel}^{D} P_{r,panel}^{\varepsilon_{r,panel}^{D}}\ \delta D_{r,panel}$$

$$-\int_{0}^{I\_out_{r,lumber}} c^{I}_{r,lumber} I\_out_{r,lumber}^{\varepsilon^{I}_{r,lumber,lumber}} \; \delta I\_out_{r,lumber}$$

$$-\int_{0}^{I\_out_{r,panel}} c^{I}_{r,panel} I\_out_{r,panel}^{\varepsilon^{I}_{r,panel,panel}} \; \delta I\_out_{r,panel} \qquad \forall\, r \qquad [2.27]$$

We propose to modify the last two elements of equation [2.18] to include variable rather than constant marginal costs as shown in equation [2.27]. The revised version is more consistent with the economic argument presented above and is likely to lead to more robust modeling results.

The material balance plus this amended objective function is all that is needed to define the problem; which can then be solved through mathematical optimization techniques. Calibration is done by altering the constants (*c*) to approximate an equilibrium condition at the base year of the base scenario.

This will have the effect of amending the ***implicit*** cost curves for processed products in the original model ([2.22] and [2.23]) to be as follows:

$$P_{r,lumber} = c^{I}_{r,lumber} I\_out_{r,lumber}^{\varepsilon^{I}_{r,lumber,lumber}} + P_{r,log}/\tau_{r,lumber} \qquad \forall r \qquad [2.28]$$

$$P_{r,panel} = c^{I}_{r,panel} I\_out_{r,panel}^{\varepsilon^{I}_{r,panel,panel}} + P_{r,log}/\tau_{r,panel} \qquad \forall r \qquad [2.29]$$

Equations [2.28] and [2.29] relate quantity of lumber and panel produced through processing in a region with local conditions through a constant, an own-price elasticity and the endogenous price of the necessary input of logs. The inclusion of variable marginal costs is more consistent with the economic argument presented above and should result in better empirical behavior.

So, we conclude that there are theoretical reasons to augment the processing components of both the common agriculture and forest sector PEMs. The next section, using a case study of a typical forest sector model, will provide empirical reasons to augment the processing component. We pay particular attention to: 1) the feasibility of using variable marginal costs in the processing component of a typical forest sector PEMs, and 2) the hypothesis that variable marginal cost components result in more robust results.

2.4 Empirical Forest Sector Case Study

Common forest sector PEMs (GFPM, CGTM, and EFI-GTM) assume a constant marginal cost for the processing sector. To understand the impact of replacing a constant marginal cost with a variable marginal cost model, we test the impacts in three ways: 1) the sensitivity of results to using a constant marginal cost to represent the processing component, 2) the ease of including quantity-price relationship in the processing sector, and 3) finally, the sensitivity of capacity utilization to the two ways of representing processing costs.

2.4.1 Model description

Before describing the methodologies employed for each test, we present the model on which these experiments ran. We started with the base year of the base scenario described in Chapter 5 of the book "The Global Forest Products Model" (Buongiorno et al. 2003). The model and the associated dataset for 14 products in 180 countries are available at: http://forestandwildlifeecology.wisc.edu/facstaff/Buongiorno/book/GFPM.htm (Buongiorno 2009). The base year represents the equilibrium condition for 1997. The availability of the GFPM software and data allow for relatively easy testing of alternative structures and

parameters, though these alterations only differ slightly from the base model. The GFPM software defines the problem using the Mathematical Programming System file format (MPS) and passes that to a Linear Programming (LP) solver that finds the solution to the problem and then passes the results back to the GFPM software for further processing.

The experiments in this paper are the result of intercepting and altering the problem as it passed between the GFPM and the LP software. The GFPM utilizes step-wise linear approximations to the area under the supply and demand curves. The objective function is implemented as follows:

$$maximize\ Z = \sum_i \sum_k \sum_d P_{ikd}\, \Delta D_{ikd} - \sum_i \sum_k \sum_s P_{iks}\, \Delta S_{iks} - \sum_i \sum_k m_{ik} Y_{ik} - \sum_i \sum_j \sum_k c_{ijk} T_{ijk} \qquad [2.30]$$

where i,j = country, k = product, d,s = step in approximation, P = price representing step, ΔD = quantity demanded at step d, ΔS = quantity supplied at step s, Y = quantity manufactured, m= cost of manufacture, T = quantity transported and c = cost of transport.

2.4.1.1 Removing enforced trade levels

In the GFPM, the base period costs are calibrated to reproduce the observed equilibrium conditions with 90% utilization in each processing component in each country. The utilization level is reinforced by fixing imports and exports. If the calibration was fully successful, removing the enforced trade levels should not change the utilization levels from their equilibrium values. Our hypothesis is that the use of constant margins in the processing component does not

result in robust behavior and is not likely to reproduce the equilibrium behavior without trade constraints.

Enforced trade levels were removed by intercepting the MPS file and deleting the upper and lower bounds of the trade related variables[3].

2.4.1.2 Replace fixed marginal costs with variable costs

The GFPM has constant marginal costs in its processing component, so we replaced it with a variable cost component. In equation [2.31], we utilized a linear approximation identical to the structure used for supply and demand:

$$maximize\ Z' =$$

$$\ldots. - \sum_{i} \sum_{k} \sum_{y} P_{iky}\, \Delta Y_{iky} \ldots. \qquad [2.31]$$

where y = step in approximation, P = price representing step and ΔY = quantity demanded at step y. The element in equation [2.31] was used in the place of the third element in the objective function defined in equation [2.30]. The calibration process aimed to generate 90% capacity utilization at the original cost (*m*). Respecting the default number of steps of 4, we used 4 steps where the first step made 80% of capacity available at 90% of *m*, 10% capacity available at between 90% and 100% of *m*, 5% capacity available at between 100% and 105% of *m* and 5% capacity available at between 105% and 110% of *m*.

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[3] The upper limit of the trade variable serves two purposes in the case of products with supply curves. It functions both as a trade boundary and as an upper limit on the product's supply curve. As such, these specific constraints were retained.

2.4.1.3 Altering a single country's lumber manufacturing costs

The GFPM also has a unique processing cost for each country and each process. We chose to alter Japan's lumber manufacturing cost, through altering the MPS file. We added a range of numbers from ± $10 cost per unit output to the original $128.71 cost. This was done for both the constant marginal cost case and the variable marginal cost case.

2.5 Results

The replacement of constant marginal costs with variable costs in the processing component of forest sector PEMs can have a significant effect on model performance. Table 2.1 demonstrates the magnitude of those effects. It illustrates, by region, the percent of lumber manufacturing occurring in countries at 100% of their capacity under different model definitions. It was produced by downloading and running the publically available GFPM software and the 'Chapter 5 Base Scenario' dataset (Buongiorno 2009). The results are for the calibrated base period of the base scenario. The column labeled 'Original' is a tabulation of the results of the original model configuration. Under this model definition no countries (0%) are at 100% of their capacity for lumber manufacturing.

In the GFPM, the base period costs are calibrated to reproduce the desired equilibrium conditions. The constant marginal costs in the processing sector are calibrated to result in 90% utilization of each process in each country. In the base period, the equilibrium condition is further enforced by fixing imports and exports. Under a robust model calibration, the equilibrium condition should not require enforced trade levels. In order to explore this, we removed the trade constraints from the original model.

Table 2.1 Using constant vs. variable marginal costs for lumber manufacturing in GFPM

Region	# of Countries	Sum of Country Capacities ('000 m3)	% of Utilization at Country Capacity		
			Original Containing Imposed Trade	Original w/o Imposed Trade	Amended w/o Imposed Trade
Africa	43	9,185	0%	56%	1%
Asia	29	106,184	0%	40%	0%
Europe	28	98,482	0%	73%	3%
Former USSR	8	28,401	0%	100%	0%
North/Central America	16	199,201	0%	2%	0%
Oceania	9	7,679	0%	54%	0%
South America	13	33,313	0%	25%	0%
Total	**146**	**482,445**	**0%**	**34%**	**1%**

(Source: author's calculations)

The column labeled 'Original w/o Imposed Trade', in Table 2.1, illustrates the effects of removing the trade constraints from the original model; the percent of lumber manufacturing occurring in countries at 100% of their capacity is 34% of global production. The most extreme change is in the region labeled 'former USSR', where in the absence of trade constraints, 100% of the countries are now running their lumber manufacturing at capacity. On theoretical grounds, we already hypothesized such instability in results.

In the column labeled 'Amended w/o Imposed Trade', in Table 2.1, we illustrate the effects of implementing variable marginal costs in the processing sector. In spite of the absence of trade constraints, only 1% of the global lumber manufacturing occurs in countries at 100% capacity. (i.e., Romania whose low manufacturing costs allow it to run at 100% capacity). The results are

closer to those intended in the calibration and represent the more stable results we theorized would be the outcome.

Figure 2.1 helps illustrates the source of the differences in volatility in the results from Table 2.1. The figure represents the robustness of Japan's lumber processing utilization to changes in processing costs using the same three model configurations. No other changes were made to the models.

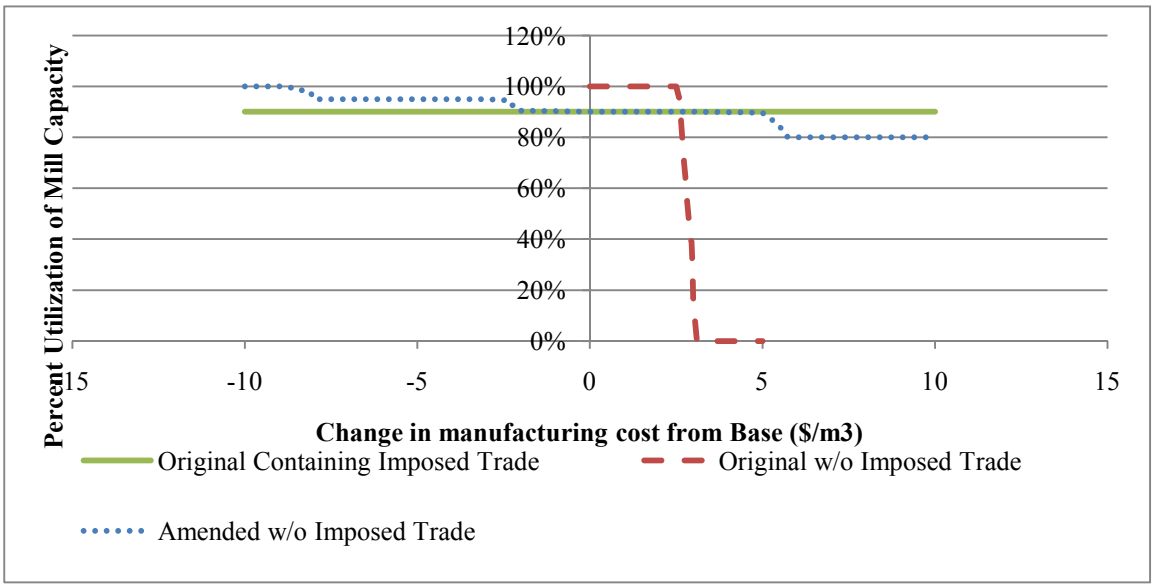

Figure 2.1. Sensitivity of utilization levels to manufacturing costs in Japan's lumber mills

Under the 'Original' model configuration, as a result of the trade constraints, Japan's lumber mill utilization remains at 90% of capacity regardless of changes to their processing cost. The 'Original w/o Imposed Trade' line represents the results of a constant marginal cost with the trade constraints removed. Under that model configuration, a change of $0.50 in the constant marginal cost induces a change in the utilization from 100% to 0%. The 'Amended w/o Imposed Trade' line represents the results of a variable marginal cost with the trade constraints removed.

Under that model configuration, a shift of over $10 in the variable marginal cost curve is required to induce a change in the utilization from 100% to 80%. Steps are still evident under the variable marginal costs. These are a result of the step-wise linearization used in implementing the model.

2.6 Discussion

The processing sectors in common agriculture and forest sector partial equilibrium models have deficiencies in how costs are represented. From a theoretical point of view we would expect the cost component to be made up of two elements. One element needs to represent the cost of endogenous products used as input into the process and the other element needs to represent all the remaining processing costs. This second element represents the aggregate behavior of a large number of processors with different production processes; and as such is best represented by a variable marginal cost element. Interestingly, agriculture sector PEMs are missing the first element and most forest sector PEMs are deficient in the second.

Common agriculture sector PEMs do not directly include the price of endogenous input products in their processing component. The prices are included as a coefficient of elasticity. This omission results in an incoherent model from a theoretical point of view, though there is no reason to expect poor results.

Common forest sector PEMs (GFPM, CGTM, and EFI-GTM) do not include variable marginal costs in their processing component. There are both theoretical and empirical reasons to reject

the use of constant marginal costs. The case study illustrates how pivotal variable marginal costs can be in ensuring robust results from a forest sector PEM.

As theory suggests, the use of constant marginal processing costs will result in much of the processing being done in countries at full capacity. Once a country can access the global export market, it will continue supplying until either it reaches its capacity or the global market is satisfied.

In our case study, despite a calibration goal of all countries producing at 90% of capacity, constant marginal costs resulted in 34% of the global production of lumber taking place in countries at full capacity. On a regional level, the nonsensical swings between 2% and 100% were the result of penny differences in the calibration process. With the inclusion of variable marginal costs, the amended model configuration resulted in only 1% of the global production of lumber taking place in countries at full capacity. As expected from theoretical considerations this represents much more robust and better empirical results.

The reason for this swing was well illustrated with Japan's lumber processing as an example. A $0.50 swing in the constant marginal processing cost resulted in a swing of processing utilization from 100% capacity to 0% of capacity. Under a variable marginal cost, it took a $10 shift in the cost curve to move the utilization from 100% of capacity to 80%. It is this robustness at the country level that leads to better results.

2.7 Conclusions

In the review of trade economic theory, it was demonstrated that the representation of the processing sector in the common agriculture and forest sector trade models could both be improved by including aspects from the other.

In agriculture trade modeling, it is our view that the common representation of the processing sector needs to be augmented by directly including the costs of endogenous input products. This replaces the indirect inclusions through the use of elasticities. The result is a theoretically more coherent processing component.

In forest products trade modeling, it is our view that the common representation of the processing sector needs to be augmented by including variable processing costs within the processing sector. This replaces the use of constant marginal costs. There are both theoretical reasons to expect this is a better representation of the component and the results are empirically more tenable.

3 Armington Elasticity and Trade Inertia Constraints in Forest Products Trade Models[4]

3.1 Introduction

Global trade models are used to predict general economic activity and especially the trade of many types of products between/among countries. Like any set of models, they have weaknesses, weaknesses that could pervert trade policy creation, implementation and evaluation. A longstanding desire is that trade models are transparent; this facilitates our ability to distinguish between data quality and model assumptions, and market behavior. The idiosyncratic use of absolute trade limits in forest products trade models breaches this dictum.

Global forest product trade modeling originated at the International Institute of Applied System Analysis (IIASA) in the early 1980s with the development of the prototype Global Trade Model (GTM-1) (Buongiorno et al. 2003). GTM-1 was used in a study of the global newsprint sector (Buongiorno and Gilless. 1984). The GTM-1 prototype was further developed by IIASA into the Global Trade Model (GTM) (Dykstra and Kallio 1987). GTM was used in the first comprehensive global forest sector analysis (Kallio et al. 1987). The IIASA GTM model has been further adapted into the CINTRAFOR Global Trade Model (CGTM) (Cardellichio and Adams 1990) and is now maintained by the Center for International Trade in Forest Products (CINTRAFOR) at the University of Washington. CGTM has been used in many environmental

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4 A version of this chapter is being submitted for publication. Northway, S., J.G. Bull and G.Q. Bull. Armington Elasticity and Trade Inertia Constraints in Forest Products Trade Models.

studies, including an examination of the role of Oregon's forests in contributing to global environmental services (Perez-Garcia 2003). Independent of the path that lead to the CGTM, the GTM-1 was developed into the Global Forest Products Model (GFPM) (Buongiorno et al. 2003). GFPM has found continued use in a wide variety of studies including work on tariff liberalization (Buongiorno et al. 2003). It is easy to see the continuing influence of these early models and their applications on models of more recent origin. The European Forestry Institute Global Trade Model (EFI-GTM) (Kallio et al. 2004) has been used to look at the economic impact of accelerating growth in European forests (Solberg et al. 2003). The International Forest and Forest Products model (IFFP) has explored the implications of China's increasing demand for forest products on Asia-Pacific trade (Northway and Bull 2006). And, the FORINTEK Global Trade Model has been used to look at the effect of an insect outbreak on the Canada-Japan trade in logs (Gaston and Marinescu 2006). All of these models have many features in common, including at least the capability of implementing trade inertia constraints.

In this context then, our purpose is to: 1) examine the implications of using trade inertia constraints in forest products trade model, 2) appraise the feasibility of using Armington elasticity (Armington 1969) to replace trade inertia, and 3) evaluate the hypothesis that Armington elasticity is more responsive than trade inertia to trading cost shocks.

3.2 Background

Global trade models use as a starting point country specific supply curves, demand curves, manufacturing costs and international trade costs (referred to here collectively as SDMT) to forecast trade patterns (Roningen 1997). The key assumptions of a model based on SDMT are

that: 1) countries will act as rational agents and try to maximize their utility, 2) products traded are homogeneous, and 3) trade changes are an instantaneous reflection of changes in SDMT. One of the logical consequences of these assumptions is that product cross-hauling[5] will not occur (Samuelson 1952).

Violation of these assumptions can lead to many shortcomings . To adapt, model builders have been forced to make adjustments to the assumptions in order to incorporate cross-hauling[6] (Armington 1969, Dykstra and Kallio 1987). The majority of the global trade models, with the notable exception of forest products trade models, use Armington elasticity (AE) (Armington, 1969) to address cross-hauling by relaxing the assumption of homogenous product. AE is implemented as an elasticity of substitution between import and domestic versions of the same product. Armington suggests cross-hauling resulted from differentiation between imported and domestic products; he rejects the idea that lags[7] in buyers' response was the primary explanation for cross-hauling, evident in observed effects but not modeling results (Armington 1969).

Since the early 1970s, there has been a significant body of literature to bolster the discussion of AE (Galloway et al. 2003). It is nearly universally found in trade models used by governments and international organizations, including the World Bank, the International Monetary Fund and the World Trade Organization (Lloyd and Zhang 2006). There remain many AE topics being currently debated, since they are seen to be possible shortcomings. They include: 1)

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[5] Cross-hauling occurs when a country simultaneously imports and exports the same product.
[6] Other modelers have focused on other 'adjustments' to the basic model.
[7] The lag in buyer response, as we shall see later, is the fundamental tenant of trade inertia [TI].

underestimation of welfare effects, 2) effect on suggested tariffs, 3) short-run vs. long-run elasticity, 4) product aggregation impacts, 5) AE commonality between countries, and 6) appropriate statistical estimation techniques (McDaniel and Balisteri 2003; Lloyd and Zhang 2006; Yilmazkuday 2009).

Forest products trade modeling took a different approach to cross-hauling starting in the 1980s. At least seven forest products trade models have been developed in the last three decades, all attempt to improve on the extant approach to policy analysis (Dykstra and Kallio 1987; Cardellichio and Adams 1990; Buongiorno et al. 2003; Kallio et al. 2004; Gaston and Marinescu 2006; Northway and Bull 2006). All model applications seek to show a linkage between a policy challenge and the fundamental of trade in forest products.

Models of the forest products sector chose a different path to deal with cross-hauling. The model builders use trade inertia (TI) to 'relax' the assumption of instantaneous reflection of changes in the SDMT. In the IIASA Global Trade Model (Dykstra and Kallio 1987), the Global Forest Products Model (Buongiorno et al. 2003) and the European Forestry Institute Global Trade Model (Kallio et al. 2004) TI constraints are used; in the CINTRAFOR Global Trade Model (Perez-Garcia 2003) it is referred to as the 'trade possibilities' constraint. Different models implement TI in slightly different ways, but the effect is consistent: a product's bilateral trade is bound between an absolute minimum and maximum, which is linked to the levels of trade in previous years. The stated rationale for TI usage is that the forest product trade models have to accommodate many preexisting contracts and industrial relationships that constrain changes in the level of trade (Dykstra and Kallio 1987; Buongiorno et al. 2003).

Despite TI and AE reflecting different assumptions, their effects on trade model results may be similar. Both methods encourage trade patterns that are not efficient under a model's basic SDMT. However, there are two key differences between TI and AE. First, TI places overt constraints on bilateral trade with upper and lower bounds while AE incorporates an elasticity of substitution between domestic and import products. Second TI has no body of literature to support the methodology or debate its shortcomings, whereas AE does. Given these differences, we wanted to assess: 1) the impact of removing the TI constraint in a representative forest product trade model, 2) the ease and efficacy of using AE as a replacement for TI, and 3) the difference in their response to trading cost shocks.

3.3 Theory

AE and TI are fundamentally different in how they affect substitution between import and domestic products. In this section, AE and TI behavior is examined through the concepts of indifference curves and budget isoquants.

Figure 3.1 illustrates a simple trade model for a country with the option to produce domestic product or import product. The indifference curves (dashed lines) indicate the perfect substitution of these products. Along the indifference curve, the same utility can be obtained by substituting a unit of the imported product for a unit of the domestic product. The further the indifference curve is from the origin the higher the level of utility. The budget isoquants (solid lines) reflect the shape of the price sensitive supply curves for the domestic and imported product. The point where the indifference curve and the budget isoquant is tangent is the theoretical optimal mix of imported and domestic products for a given budget.

Under the model illustrated in Figure 3.1, there will be no cross-hauling at equilibrium because the domestic and import product are perfect substitutes. If cross-hauling exists, prior to reaching equilibrium, an opportunity exists for arbitrage. As the products are assumed to be perfect substitutes, trade costs can be eliminated by substituting the exported domestic product for the foreign import. This substitution continues until either the exports or imports are exhausted, at which point there are either imports or exports, but not both.

The budget isoquant shifting right represents the effect of a budget shock, the result from a change in the budget allocated to this product. The shift implies an increase in imported and domestic products at a new optimum. The relative increase in consumption of imported and domestic products will depends on the relative prices of these products.

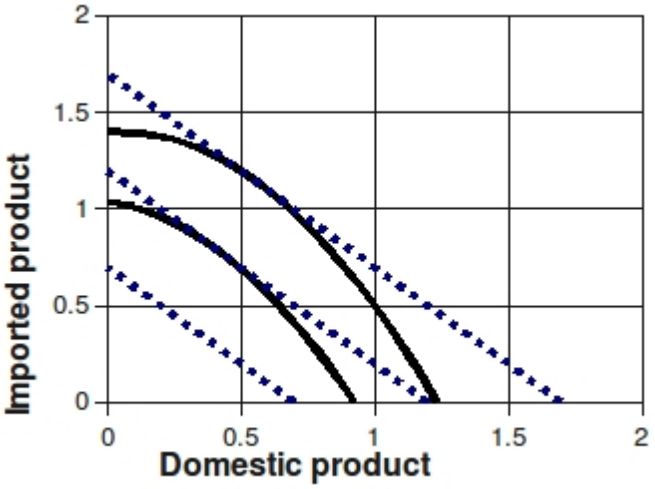

Figure 3.1 Indifference curves and budget isoquants

There are obvious limitations in a SDMT model (see Figure 3.1). First, products are assumed to be homogeneous, there is no allowance for differentiation between import and domestic

products. Second, trade changes are assumed to be instantaneous, allowing no long term contracts or agreements.

For trade analysis, more complex trade model structures have been developed and used; in essence, modifications of the SDMT model. Two common modifications made are: 1) Trade Inertia constraints (TI), and 2) Armington elasticity (AE). TI has been confined to usage in forest products trade models and AE to a wide range of other trade models. TI is an absolute or forced constraint on the annual variation in levels of bilateral trade. In contrast, AE provides an elasticity of substitution between a domestic product and its imported analogue.

Figure 3.2 shows the indifference curves implied by TI constraints on trade. The boundaries set are .2 units and 1 unit; these are minimum and maximum import levels set in the model. It means, for example, that if the minimum boundary on imported products is set at .2, no amount of the domestic product can substitute for the imported product below .2. If the boundary for the maximum level of imports is set to 1 unit, no increased amount of imports can substitute for the domestic products above 1. Between the minimum and maximum, there is perfect substitution between import and domestic products.

Under the TI model illustrated in Figure 3.2, there is the potential for cross-hauling at equilibrium due to TI boundaries. In the case where the domestic producers are exporters, the minimum import boundary will still generate imports. At the boundary points in the utility curve, the domestic and import products are not perfect substitutes can produce cross-hauling.

Figure 3.2 also shows a budget shock, a shift right of the budget line, representing a change in the budget allocated to the product. The shift to the right may imply an increase in imported and

domestic products at a new optimum. The relative increase in consumption of imported and domestic products will depend on relative price of these products and the TI boundaries. If the optimum mix of products was already at the TI-imposed maximum, then the budget shock will not result in increased imports. If the optimum mix of products was already at a minimum TI boundary, the shift of the budget line is to the left will not produce a decrease in imports

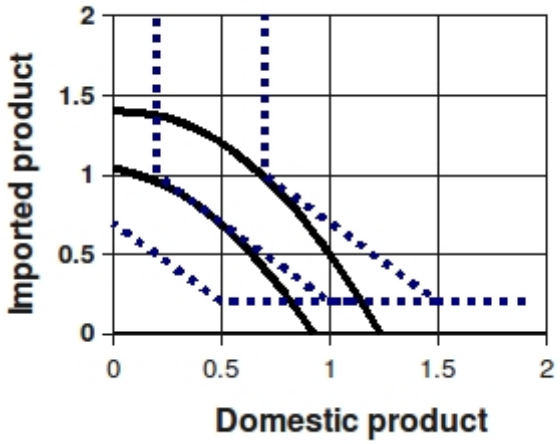

Figure 3.2 Trade inertia indifference curves and budget isoquants

Figure 3.3 shows the indifference curves implied by AE. The curves represent elasticity of substitution between domestic and imported products. In contrast to the simple model in Figure 3.1, substitution is imperfect and in contrast to the TI model in Figure 3.2, imported products and domestic products are mutual substitutes at all levels.

Under the AE model illustrated in Figure 3.3, there is the potential for cross-hauling at equilibrium because of the AE assumption of imperfect of substitution. For example, cross-hauling would occur under the following conditions: 1) the domestic producers are exporters

because of a global competitive advantage, 2) an increase of half a unit of the import product has the same utility as an increase of 1 unit of the domestic product, and 3) the price of the import product is less than twice the price of the domestic product. Utility is maximized by a combination of the domestic and import product independent of the domestic producer's ability to export. Because the domestic and import products are not perfect substitutes cross-hauling can exist at equilibrium.

The budget shock in Figure 3.3, a shift to the right, leads to an increase in consumption of imports and domestic products at a new optimum. The relative increase in consumption of imported and domestic products depends on the relative prices of these products and the AE elasticity of substitution. In contrast to the TI model in Figure 3.2, the change in the level of imported products is more responsive since the absolute boundaries in TI are not found in AE.

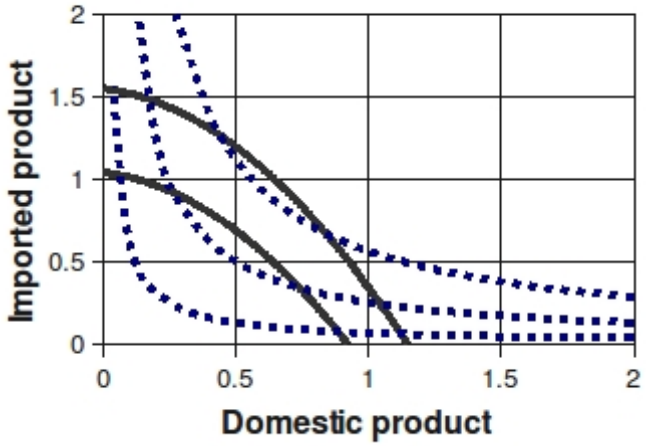

Figure 3.3 Armington elasticity indifference curves and budget isoquants

Figure 3.4 shows AE-like indifference curves that we test later in the GFPM[8]. These curves represent a linear approximation of AE, combining perfect substitution within boundaries that change in proportion to consumption of the domestic product. In the example, the minimum boundary for imports is set at one-third the consumption of the domestic product, while the maximum boundary for imports is set at three times the consumption of the domestic product. Although imports are between a third and three times consumption of the domestic product, there is perfect substitution between imported and domestic products.

In contrast to the simple model in Figure 3.1, perfect substitution only exists between the defined boundaries and in contrast to the model in Figure 3.2, the boundaries are proportional to the consumption of the domestic product rather than being fixed to an absolute minimum and maximum level. In contrast to the AE model in Figure 3.3, it is a combination of perfect substitution with boundaries as opposed to a continuous elasticity of substitution.

Under the AE-like model illustrated in Figure 3.4, there is the potential for cross-hauling at equilibrium because of the AE-like assumption of imperfect of substitution. The boundaries of the AE-like model represent elasticities from perfectly elastic to perfectly inelastic. As in AE, cross-hauling would occur under the following conditions: 1) the domestic producers are exporters because of a global competitive advantage; 2) an increase of half a unit of the import product has the same utility as an increase of 1 unit of the domestic product; and 3) the price of

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[8] A more complete representation of AE would involve a demand curve for a composite product made up of the domestic and imported versions and a series of processes to generate composites with alternative proportions. While there would be no cost to the process that generated the proportion being calibrated, alternative proportions would be costed to represent the AE. This would require more significant alterations to the GFPM than I was willing to attempt, but has been included in the IFFP as referred to in Chapter 5.

the import product is less than twice the price of the domestic. Utility is maximized by a combination of the domestic and imported products regardless of the domestic producer's ability to export. Because the domestic and import products are not perfect substitutes, cross-hauling can exist at equilibrium.

In Figure 3.4 the budget isoquant line shifting to the right implies an increase in imported and domestic products at a new optimum. The relative increase in consumption of imported and domestic products depends on relative price of these products and boundaries that are determined by the consumption of the domestic product. In contrast to the use of TI in Figure 3.2, the change in the level of imported products is more responsive since there are no absolute boundaries as found in TI. In contrast to the use of AE in Figure 3.3, the change in the level of imported products is less responsive to the budget shock because of the linear approximation.

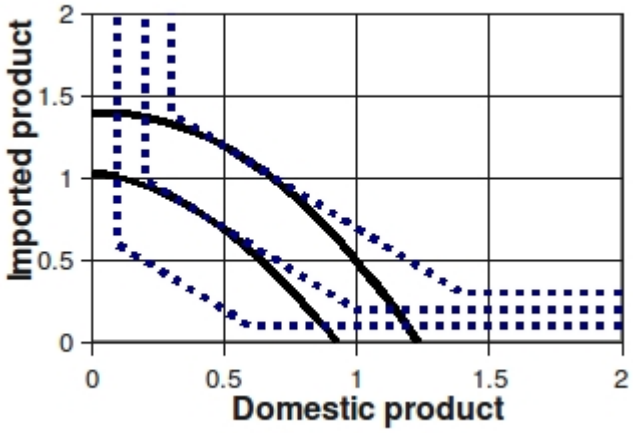

Figure 3.4 Linear approximation of Armington elasticity utility and budget isoquants

So far we have explored alternatives to the 'ideal world' embodied in the assumption of prefect substitution between domestic and imported products. In reality, there is cross-hauling of products. To deal with cross-hauling we have explored three approaches, TI, AE and AE-like. It is clear that TI minimum and maximum boundaries limit the responsiveness to budget shocks. In addition, AE has been demonstrated to be more responsive than TI. Finally, AE-like responses can be viewed as intermediate between TI and AE.

3.4 Case Study

TI and AE can both deal with challenges in forest products trade modeling. To understand the impact of the TI and AE method, we analyze how TI affects the performance of a model. Then we examine how AE could operate as an alternative. Finally, we compare how TI and AE respond to an economic shock.

3.4.1 Model description

Before we describe the methodologies employed for each test, we will describe how we built the model on which these experiments ran. We started with the base scenario described in Chapter 5 of the book "The Global Forest Products Model" (Buongiorno et al. 2003). The model and the associated dataset for 14 products in 180 countries are available at a website: http://forestandwildlifeecology.wisc.edu/facstaff/Buongiorno/book/GFPM.htm (Buongiorno 2009). The base model develops annual projections for the 13 years from 1998 to 2010. The availability of the GFPM software and data allow for relatively easy testing of alternative structures and parameters, though these alterations only differ slightly from the base model. The GFPM software defines the problem using the Mathematical Programming System file format

(MPS) and passes that to a Linear Programming (LP) solver that finds the solution to the problem and then passes the results back to the GFPM software for further processing. The experiments in this paper are the result of intercepting and altering the problem as it passed between the GFPM and the LP software.

3.4.2 Modeling TI and AE

In forest products trade models we decided to test the impacts of three critical issues: removing TI from the model, substituting TI with 'AE-like' and finally, examining the influence of a trading-cost shock[9].

3.4.2.1 Remove TI

We wanted to explore the importance of TI constraints to forest product trade model performance. By removing TI from a typical forest product trade model, we can understand the role of TI. In the GFPM, TI is implemented by incorporating a penalty into the objective function for exceeding the trade limits. The original constraints are shown in equation [3.1]:

$$T_{ijk} + \Delta T_{ijk}^{L} \geq T_{ijk}^{L} \qquad \forall\, i,j,k$$

$$T_{ijk} - \Delta T_{ijk}^{U} \leq T_{ijk}^{U} \qquad \forall\, i,j,k \qquad [3.1]$$

where: i,j = country, k = product, T = amount traded, T^L, T^U = lower and upper trade limits and ΔT^L, ΔT^U = amount by which trade falls short of the lower bound, or exceeds the upper bound. These two variables appear in the objective function in equation [3.2]:

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[9] The trading cost shock tests our hypothesis that 'AE-like' techniques will be more responsive to policy measures.

$$maximize\ Z = \ldots - \sum_i \sum_j \sum_k P_{k,-1} \left(\Delta T_{ijk}^L + \Delta T_{ijk}^U \right) \ldots \qquad [3.2]$$

where $P_{k,-1}$ is the penalty for exceeding the trade limits (set to the previous year world price). To evaluate the impact of removing the TI constraint we simply substitute a 0.0 cost for each $P_{k,-1}$[10] in the objective function. A 0 cost for violating the TI boundary constraints is a programmatically simple way to accomplish the same effect as removing the constraints from the model.

3.4.2.2 Replace TI with AE-like

We explore the possibility and implications of replacing TI with AE in forest trade models, using the GFPM as a representative model and using the same base scenario. The AE-like constraint, discussed above, was implemented as a linear approximation of AE. The AE-like constraints allow perfect substitution between the domestic and imported products within boundaries that are proportional to the total consumption of the product.

Table 3.1 shows the product specific Armington elasticities used in our AE-like replacement of TI (Gan 2006). The AE-like constraints limit the product's imports to being between a minimum and maximum fraction of that products total consumption. We set the minimum boundary at the previous year's ratio of imports to consumption minus the ratio times 0.05 times the tabulated elasticity; and we set maximum boundary at the previous year's ratio of imports to consumption

[10] The upper limit of the trade inertia boundary serves two purposes in the case of products with supply curves. It functions both as a trade inertia boundary and as an upper limit on the product's supply curve. As such, these specific constraints were retained.

plus the ratio times 0.05 times the tabulated elasticity. For example, if industrial roundwood imports made up .25 of total consumption in the previous year, this year's minimum ratio of industrial roundwood imports to total consumption would be set to 0.238 = 0.25*(1.0-0.05*0.923) and the maximum ratio would be set to .262 = 0.25*(1.0+0.05*0.923). The choice of "0.05" is somewhat arbitrary, and was chosen to approximate the TI boundary for industrial roundwood under a constant level of consumption.

Table 3.1 Forest product Armington elasticity

Product Type	Armington Elasticity (α)
Industrial round wood	0.923
Lumber	0.532
Wood based panels	1.370
Wood pulp	0.438
Recovered paper	0.613
Newsprint	0.247
Printing and writing paper	1.367
Other paper	0.973

(Source: Gan 2006)

We implemented the AE approximation differently based on the particular combination of product type and whether we were manipulating imports or exports. Firstly, imports of products that have a domestic demand curve are affected by the total domestic consumption. Second, imports of products that are used in domestic manufacturing are affected by the total domestic use of that product in manufacturing. This use is now common in trade models (Lloyd and Zhang 2006). Third, exports of products that have a domestic supply curve are affected by the amount of domestic supply. The application of the idea to exports rather than imports has been

introduced (Dervis et al. 1982) and is referred to as applying a 'transformation function' between products destined for domestic use or export. We will refer to it under the rubric AE, as both concepts have weakly separated markets for traded and domestic products. Finally, exports of products that are produced from domestic manufacturing are affected by production levels. This can also be referred to as applying a transformation function, but we will refer to it as AE.

The AE approximation for imports with local demand curves required altering the "L" and "U" rows of the MPS file, as shown in equation [3.3]:

$$T_{ijk} + \Delta T_{ijk}^{L} \geq T_{ijk,-1}\left(\frac{D_{ik}}{D_{ik,-1}}\right)(1 - 0.05\alpha_k) \qquad \forall\, i,j,k$$

$$T_{ijk} - \Delta T_{ijk}^{U} \leq T_{ijk,-1}\left(\frac{D_{ik}}{D_{ik,-1}}\right)(1 + 0.05\alpha_k) \qquad \forall\, i,j,k \qquad [3.3]$$

where: D_{ik} , $D_{ik,-1}$ = product demand in the current and previous period, and α_k = Armington elasticity. The two penalty variables, ΔT^L, ΔT^U, appear as before in the objective function.

Similarly, an AE approximation can be accomplished for imports and exports of products with a local supply curve through altering their "L" and "U" rows of the MPS file as shown in equation [3.4]:

$$T_{ijk} + \Delta T_{ijk}^{L} \geq T_{ijk,-1}\left(\frac{S_{ik}}{S_{ik,-1}}\right)(1 - 0.05\alpha_k) \qquad \forall\, i,j,k$$

$$T_{ijk} - \Delta T_{ijk}^{U} \leq T_{ijk,-1}\left(\frac{S_{ik}}{S_{ik,-1}}\right)(1 + 0.05\alpha_k) \qquad \forall\, i,j,k \qquad [3.4]$$

where: S_{ik}, $S_{ik,-1}$ = raw material supply of the product in the current and previous period, respectively. The two penalty variables, ΔT^L, ΔT^U, appear as before in the objective function.

Again similarly, an AE approximation can be accomplished for imports of intermediate products of manufacturing with neither a local demand nor supply curve as well as for exports of intermediate products of manufacturing without a supply curve through altering their "L" and "U" rows in the MPS file as shown in equation [3.5]:

$$T_{ijk} + \Delta T_{ijk}^{L} \geq T_{ijk,-1}\left(\frac{Y_{ik}}{Y_{ik,-1}}\right)(1 - 0.05\alpha_k) \qquad \forall\, i,j,k$$

$$T_{ijk} - \Delta T_{ijk}^{U} \leq T_{ijk,-1}\left(\frac{Y_{ik}}{Y_{ik,-1}}\right)(1 + 0.05\alpha_k) \qquad \forall\, i,j,k \qquad [3.5]$$

where Y_{ik}, $Y_{ik,-1}$ = the quantity of the product manufactured in the current and previous period, respectively. The two penalty variables, ΔT^L, ΔT^U, appear as before in the objective function.

3.4.2.3 Trading cost shock

Next we compared the relative responsiveness of TI and AE to an economic shock. Using the base scenario of the GFPM already described, we compared the TI model's response with the AE-like model's response. We also chose to introduce a trading-cost shock[11]. This shock could represents a sudden increase in protective tariffs or an increase in transport costs due to either increased fuel costs or a disruption of the transportation network. In the GFPM, trading costs are implemented as an element of the objective function, as shown in equation [3.6]:

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[11] Trading costs include transportation costs and tariffs/duties/taxes.

$$maximize\ Z = \ \ldots - \sum_i \sum_j \sum_k c_{ijk}\, T_{ijk} \ldots \qquad [3.6]$$

where: *i,j* = country, *k* = product, c = trading costs, and *T* = amount traded.

The trading-cost shock was implemented by replacing the coefficients of the original trading cost variables (c_{ijk}) found in the objective function within the MPS file with ($m*c_{ijk}$), where *m* was varied from 1 to 4. When *m*=4, trading cost increase up to four times the base.

3.5 Results

TI removals, TI replacement with AE and trading cost shock can all have a significant effect on model performance. The following results demonstrate the magnitude of those effects.

3.5.1 TI impacts

Figure 3.5 shows projections of imports of industrial round wood by region from the unaltered GFPM model (our TI model). It was produced by downloading and running the publicly available software and the "Chapter 5 Base Scenario" dataset (Buongiorno 2009). Up to 1997 the figures are historical; post-1997 they are projections. Each region exhibits relatively smooth transition between the historical and projected levels of industrial round wood imports.

Under TI projections, the large industrial round wood imports to Asia and Europe continue a slow increase to 2010, while Asia and Europe surpass historic highs. The relatively modest imports to the North/Central America region continue to increase.

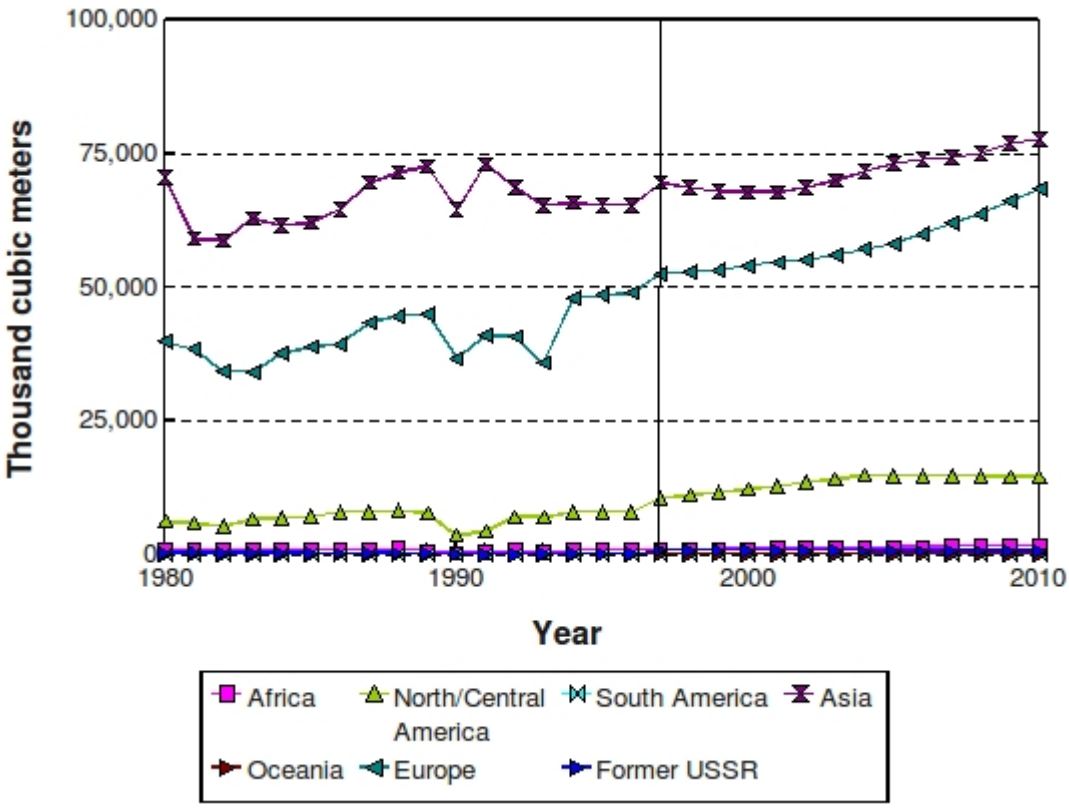

Figure 3.5. Imports of industrial roundwood under trade inertia (TI)

Figure 3.6 demonstrate the impact of removing the TI constraint from the original GFPM scenario as shown in Figure 3.5. The only difference in model structure and parameters between Figure 3.5 and Figure 3.6 is the removal of the TI constraint indicated in equations [3.1] and [3.2]. The predictions with a 'no TI' constraint now reflect the fundamental supply, demand, manufacturing costs and trade relationships[12] in the model. In particular, the 'no TI' scenario assumes that imports, exports and domestic versions of the same products are all perfect substitutes.

[12] As noted earlier the SDMT parameters of the model.

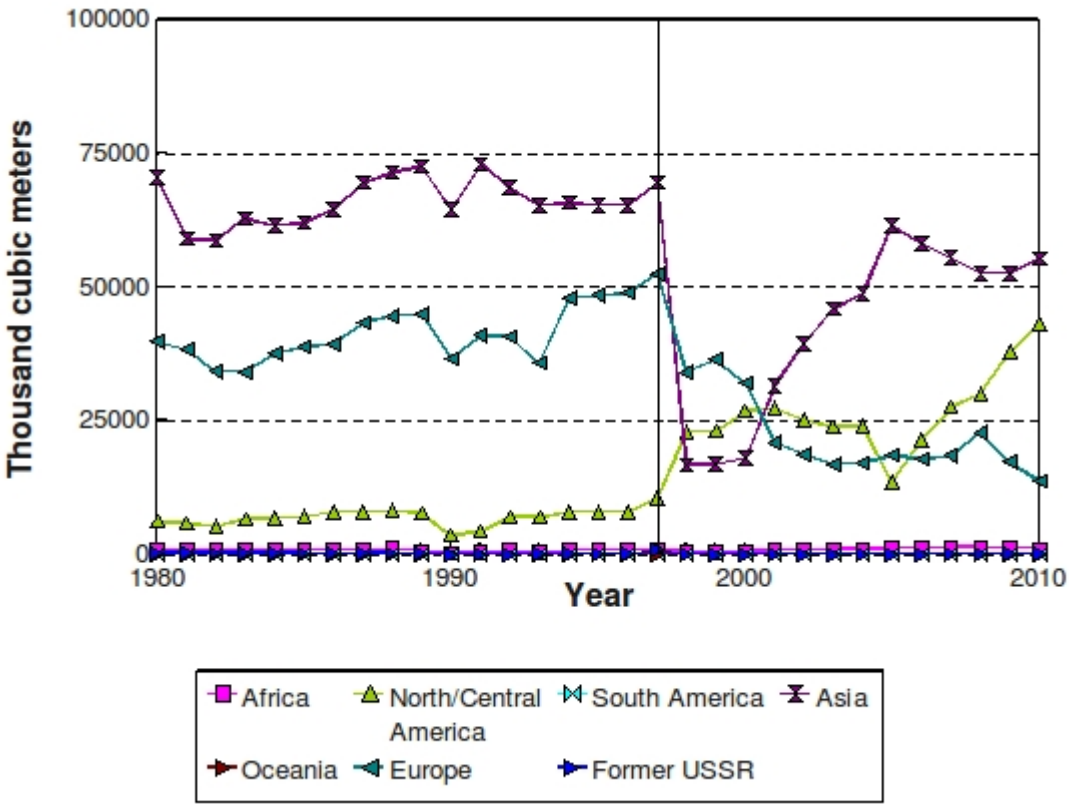

Figure 3.6. Imports of industrial roundwood after removing trade inertia constraints (no TI)

With 'no TI' constraints, the projections are obviously disconnected from historic patterns of trade. As seen in Figure 3.5, the effects of the TI constraints are evident when you compare the 1997 historical trade, or the 1998 TI predictions with the 1998 predictions in this 'no TI' model, as illustrated in Figure 3.6. Differences in predictions beyond that are confounded with other dynamic components in the model.

In addition, Figure 3.6 shows dramatically different projections, for industrial round wood imports, when compared to either the TI based results in Figure 3.5 or historical trends. Predicted

imports for Asia and Europe are much lower in the absence TI; while North/Central American imports are much higher.

3.5.2 AE impacts

In Figure 3.7 the TI constraint is replaced with an AE-like constraint. It is clear that we can replace TI with AE-like within the GFPM and generally reproduce the trade patterns as seen in Figure 3.5. As noted for Figure 3.5, the Asian industrial round wood imports are predicted to be stable while European imports are projected to reach previously unattained levels.

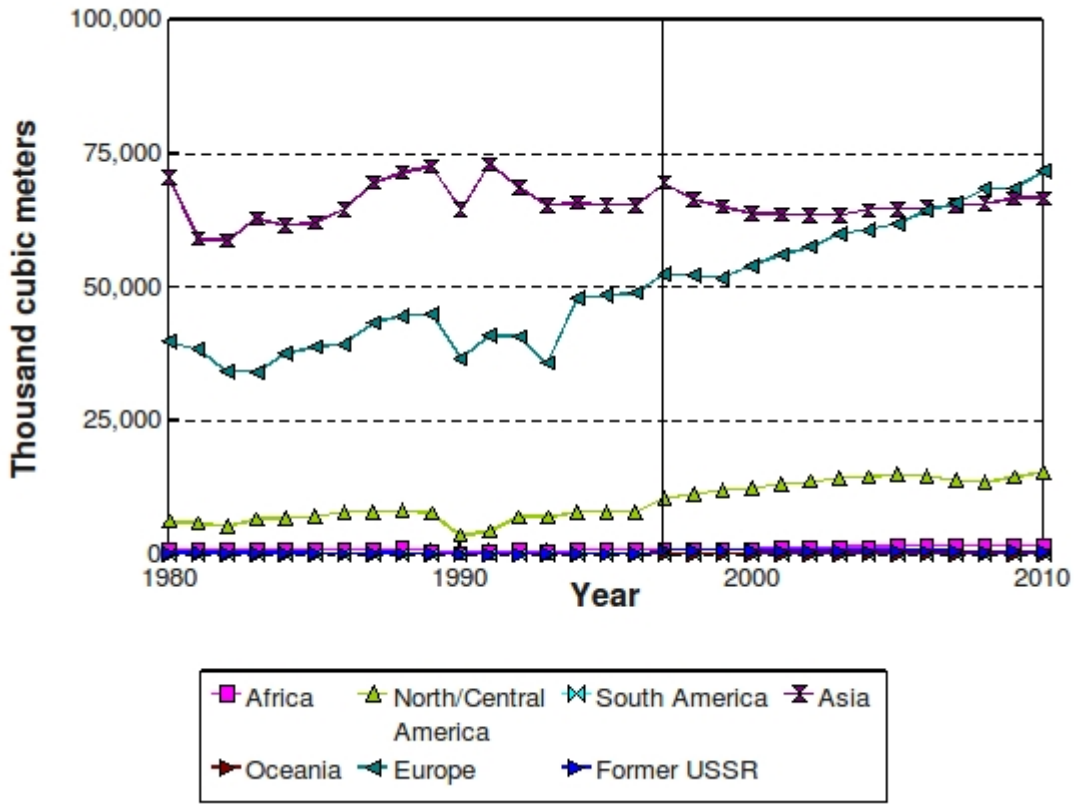

Figure 3.7 Imports of industrial round wood applying Armington Elasticity (AE-like).

3.5.3 Trading-cost shocks

Figure 3.8 is the result of testing the relative responsiveness of TI and AE to a trading-cost shock. The response to the shock was measured as the global industrial roundwood imports, expressed as a fraction of the results without the shock. The graphed results are for the third year of the projection. This time was selected as being sufficiently long to give time for adjustment while short enough to minimize the confounding impacts of other model components.

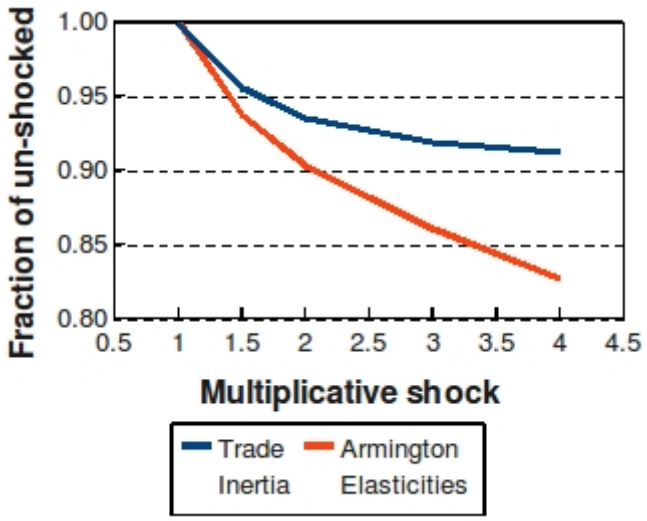

Figure 3.8. Effect of a trading-cost shock on subsequent industrial roundwood imports.

In Figure 3.8, the x-axis represents the magnitude of the trading-cost shock, with 4 indicating an increase of trading costs by a factor of 4. The y-axis represents the impact of the shock on global trade in industrial roundwood by expressing it as a fraction of the results without the shock. The TI model results are not as responsive to trading-cost shocks as AE-like model results. For example, a doubling of trade costs under the TI model resulted in 94% of the original industrial round wood imports, while under the AE-like model the reduction was to 82%.

3.6 Discussion

The TI (or alternatively AE) cases examined illustrate how pivotal TI or AE can be in influencing forest products trade model performance. If they are absent, there is no continuity between past behaviour and model projections. If they are present, the fundamental supply, demand, manufacturing costs and trade relationships in the model are muted.

TI is only used in forest products trade models while AE has become the norm in models used by governments and international organizations (Lloyd and Zhang 2006). The rationales provided for using TI and AE are different: TI was used to reflect the trade inertia generated from long-term contracts; in contrast, AE was used to reflect product differentiation based on country of origin. However, their effects on trade model results are similar; they restrict the substitutability of domestic and imported products, thereby altering trade patterns.

There is a wealth of AE literature examining its influence on trade models. [13] We have demonstrated that AE can be used to replace TI constraints in the structure of a typical forest products trade model. In our example, the base scenario results were similar but we demonstrated that AE is more responsive to an economic shock.

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[13] For example, studies suggest that the use of AE generally encourages higher optimal tariffs and underestimates the welfare effects of policies that encourage trade (McDaniel and Balistreri 2002). The same concerns have not been raised about TI, only because no such body of literature exists.

Though not explored in our case, we have concerns that TI or AE-like components in trade models affects results that cannot be justified by the rationales used for their inclusion. We believe they are capable of masking deficiencies in the model structure and data. Specifically, they mask: 1) granularity in product definition, 2) granularity of the model construction, and 3) poor model parameterization.

The granularity in product definition is often the result of poor data availability. Global trade models are based on aggregate product definitions that contain little of the nuance that may exist inside a product category. These data sets often exhibit cross-hauling where the disaggregated product would not. As mentioned, cross-hauling is not consistent with the assumptions behind a SDMT trade models. Therefore TI/AE can mask the problem by forcing imports and exports where they would not happen for basic economic reasons.

The granularity in the model structure, at least in the case of GPFM, is illustrated with a focus on manufacturing costs. The manufacturing costs are invariant with a country's capacity utilization, generally leading to a country running either at full capacity if it can meet the international price, or running only at a level to meet domestic demand if the price is lower than international price. We feel this is a poor reflection of the underlying economics of the forest products industry, where the impact of an incremental change in global price affects every country's utilization of manufacturing capacity.

Finally, TI and AE can mask poor model parameterization. For example, if a country's supply, manufacturing or trade-cost coefficients are poorly estimated, the resulting model may predict no

exports. TI/AE could mask the poor estimation by forcing close to historic levels of imports and exports.

For researchers exploring the nuances of trade models, they could review a scenario without TI or AE in order to help judge how dependent the results are to their inclusion. They could also continue to refine the data and the model structures with a goal of eliminating the need for TI or AE.

Ideally, neither TI nor AE would be required in a forest products trade model. For example, future forest product trade models could include long-term contracts to replace TI's ostensible function, eliminating its potential to distort results. Future models could also improve the granularity of product definition to obviate the need for AE's differential treatment of import and domestic products (Lloyd and Zhang 2006). At present, both of these proposed solutions have data requirements that are beyond the reach of trade modelers. Therefore AE, in particular, will find continued use.

3.7 Conclusions

In reviewing the economic theory of trade, we demonstrated that to reflect cross-hauling, either trade inertia (TI) or Armington elasticity (AE) components are necessary. The case study illustrates how TI or AE can influence trade model results; in their absence, projections are disjointed from historic patterns.

Given the quality of data available for forest products trade modeling; we will continue to use TI or AE for some time. In these models, it is our view that TI could be replaced with a linear

approximation to AE (i.e. AE-like). AE has two advantages over TI: 1) AE has a body of literature related to its estimation and use that is not available for TI; and 2) AE is more responsive to trade shocks than TI.

4 Are a Country's Corruption and Development Related? : A Longitudinal Cross-Lagged Structural Equation Model Analysis[14]

4.1 Introduction

To assist developing countries, it has been the official policy of many aid agencies and development banks to alleviate poverty through promoting economic development and reducing corruption (United Nations 2009a; World Bank 2009; International Monetary Fund 2010). The agencies and banks continue to use Gross Domestic Product per capita (GDP per capita) as a main indicator of economic development and have identified corruption as a key impediment to improving a country's economic growth (International Monetary Fund 2000; United Nations 2009b; World Bank 2009). To encourage countries to reduce corruption they undertook two key strategies: First, they prioritized aid to countries demonstrating 'good' governance, and second, they made economic development loan provisions which require recipients to limit corruption (Kaufmann and Kraay 2002; Kurtz and Schrank 2007). Clearly, many international agencies see a cause-effect link between corruption and economic development.

Researchers have been long searching for a better understanding of these linkages. Their study results can be placed in two broad categories: theory and empiricism. The general conclusions,

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14 A version of this chapter has been accepted for publication. Northway, S. and G.Q. Bull. 2011. Are a Country's Corruption and Development Related? : A Longitudinal Cross-Lagged Structural Equation Model Analysis. Journal of Academy of Business and Economics.

from a theoretical perspective, are that corruption could retard economic growth through, for example, generating sociopolitical instability (Mo 2001), encouraging bureaucratic processes specifically to support corruption (Jain 2001) and reducing openness to trade (Pellegrini and Gerlagh 2004). The argument that corruption could provide a minor stimulus for economic growth has been mostly rejected (Jain 2001; Mo 2001; Pellegrini and Gerlagh 2004).

There are also theoretical reasons to conclude that high economic growth could lead to reduced corruption. For example, economic growth helps to pay for the monitoring necessary to identify corrupt practices, it strengthens the political institutions which can control corrupt behavior and it reduces the discrepancy between corrupt and legitimate income earners (Jain 2001).

The empirical studies' results are less clear, especially on the cause-effect relationship between corruption and economic growth. Mauro (1996), Gupta et al. (1998), Mo (2001) and Pellegrini and Gerlagh (2004) concluded that high levels of corruption lead to lower economic growth. Mauro (1996) and Gupta et al. (1998) utilized cross-section data and Two-Stage Least Squares (2SLS) with instrumental variables (to deal with possible biases due to endogenous variables) to demonstrate a significant negative relationship between corruption and economic growth. Mo (2001) and Pellegrini and Gerlagh (2004) utilized cross-sectional data and 2SLS with transmission channels to demonstrate a significant negative relationship between corruption and economic growth.

In contrast, Kurtz and Schrank (2007) established the opposite cause-effect pathway, that is: high economic growth leads to reduced corruption. Their divergent analysis was based on time-series cross-sectional data and a General Linear Model (GLM), which allowed them to test for a

relationship between corruption and future development growth (rather than co-temporal growth). They found no significant relationship between corruption and future economic growth, though they found evidence that development can lead to a reduction in corruption. They also suggest that many of the conclusions from previous studies, which found a corruption/economic growth cause-effect pathway, are an artifact of using a combination of cross-section data with OLS or 2SLS with instrumental variables.

To add to the confusion, Kaufmann and Kraay (2002) found what may be a feedback loop between corruption and development, suggesting that increased economic development could lead to short-term increases in levels of corruption, as more money is available to foster it.

Despite the confusion, most analysts agree that there is a very strong negative correlation between measures of existing corruption and existing economic development (Kurtz and Schrank 2007). However, the negative correlation does not explain how changes in corruption will affect development, or how changes in development will affect corruption. Given that the theoretical arguments and empirical evidence showing complex linkages in the cause-effect pathways, the links between corruption and economic growth requires further investigation.

The objective of the paper, then, is to look for further empirical evidence on both the existence and direction of cause-effect linkages between corruption and economic development. The study represents a unique contribution in its application of Structural Equation Modeling (SEM) to the problem.

4.2 Data

The measure of corruption is based on a 'perceived' corruption index. The data set used to indicate corruption was taken from Transparency International's Corruption Perception Index (CPI) (TI 2008). The CPI is a 'pole of poles' based on surveys of experts and businesses and their perception of corruption in the public officials and politicians of a particular country. Annual figures are available from 1995, starting with 41 countries and increasing to over 180 countries by 2007. The index ranges from 0 to 10, with 0 indicating a high level of perceived corruption.

The economic development indicators are from the GDP per capita statistics provided by the USDA Economic Research Service (USDA 2008). They are based on GDP per capita expressed in nominal, year 2000, $US. Complete data was available for 80 countries. The combined data was summarized at 4 points in time: 1998, 2001, 2004, and 2007; this naturally resulted in the observations of three periods of change. Logarithmic transformations were completed on the CPIs and GDP per capita; Changes were calculated as the differences in the transformed observations.

Table 4.1 shows the correlation matrix for these variables. The strongest correlations are between existing levels of GDP per capita (D_n) and existing levels of CPI (C_n); their positive sign implies that high levels of GDP per capita are associated with high levels of CPI (i.e. low levels of corruption).

Table 4.1 Correlations, means and standard deviations of log transformed GDP per capita (D) and CPI (C) for 80 countries and 4 time periods.

	1998				2001				2004				2007	
	D_1	ΔD_{1-2}	C_1	ΔC_{1-2}	D_2	ΔD_{2-3}	C_2	ΔC_{2-3}	D_3	ΔD_{3-4}	C_3	ΔC_{3-4}	D_4	C_4
1998														
D_1	1.00													
ΔD_{1-2}	0.10	1.00												
C_1	0.82	0.15	1.00											
ΔC_{1-2}	0.27	0.02	-0.06	1.00										
2001														
D_2	1.00	0.15	0.82	0.27	1.00									
ΔD_{2-3}	-0.20	0.61	-0.17	0.06	-0.17	1.00								
C_2	0.88	0.15	0.94	0.29	0.88	-0.14	1.00							
ΔC_{2-3}	-0.10	0.35	-0.11	-0.21	-0.08	0.28	-0.17	1.00						
2003														
D_3	1.00	0.18	0.82	0.28	1.00	-0.12	0.88	-0.07	1.00					
ΔD_{3-4}	-0.15	0.38	-0.25	0.20	-0.13	0.74	-0.17	0.14	-0.10	1.00				
C_3	0.86	0.24	0.93	0.24	0.87	-0.07	0.97	0.07	0.87	-0.14	1.00			
ΔC_{3-4}	-0.24	0.00	-0.31	-0.23	-0.24	0.26	-0.37	0.08	-0.23	0.21	-0.36	1.00		
2007														
D_4	0.99	0.19	0.81	0.28	1.00	-0.09	0.87	-0.06	1.00	-0.05	0.87	-0.22	1.00	
C_4	0.86	0.25	0.91	0.20	0.87	-0.02	0.94	0.09	0.87	-0.10	0.98	-0.15	0.87	1.00
mean	8.180	0.064	1.489	-0.015	8.244	0.077	1.473	0.003	8.321	0.105	1.476	0.036	8.426	1.512
SD	0.173	0.009	0.056	0.020	0.174	0.008	0.058	0.014	0.173	0.007	0.057	0.012	0.173	0.054
EXP(mean)	3568		4.43		3805		4.36		4111		4.38		4565	4.54

(Source: author's calculations)

The negative correlation between $\Delta D_{3\text{-}4}$ and the previous levels of GDP per capita; reflects the often observed 'convergence tendency' of economies; i.e. a tendency for less productive economies to grow quickly as they adopt technology from more productive economies (Mo 2001; Kurtz and Schrank 2007). There is also a negative correlation between $\Delta C_{3\text{-}4}$ and the previous levels of CPI. We think that this is another 'convergence tendency', where a country with a very low level of corruption will find it hard to continue improving corruption performance.

The negative correlation between $\Delta D_{3\text{-}4}$ and previous levels of CPI implies high CPI scores (i.e. low levels of corruption) are associated with low levels of growth in GDP per capita. This unwelcome result is likely a reflection of the strong positive correlation between CPI and GDP per capita, and GDP per capita convergence tendencies.

Figure 4.1 illustrates the end points of the data used in this study. The axes are logarithmic to help linearize the relationship and to spread out the points in this graph. The points in 1998 are labeled with a 3-letter country code based on ISO 3166-1 alpha-3 codes (UN 2008). The 1998 points are also coded, countries with a subsequent increase in CPI (green dot) and those with a neutral or decreasing trend (red dot). Solid lines connect a country's 1998 observation (dot) to its 2007 observation (arrowhead).

Figure 4.1 illustrates several important relationships: First, there is a high correlation between CPI and GDP per capita; high CPI values (lower levels of corruption) are associated with higher GDP per capita. Second, there is a tendency for higher levels of growth in GDP per capita to be associated with lower initial levels of GDP per capita. Third, and finally, there is a 'normal' level

of CPI for a given level of GDP per capita. Generally, countries with increasing corruption (red dots) are less corrupt than the 'norm' in 1998; and generally, countries with decreasing corruption (green dots) are more corrupt than the 'norm' in 1998.

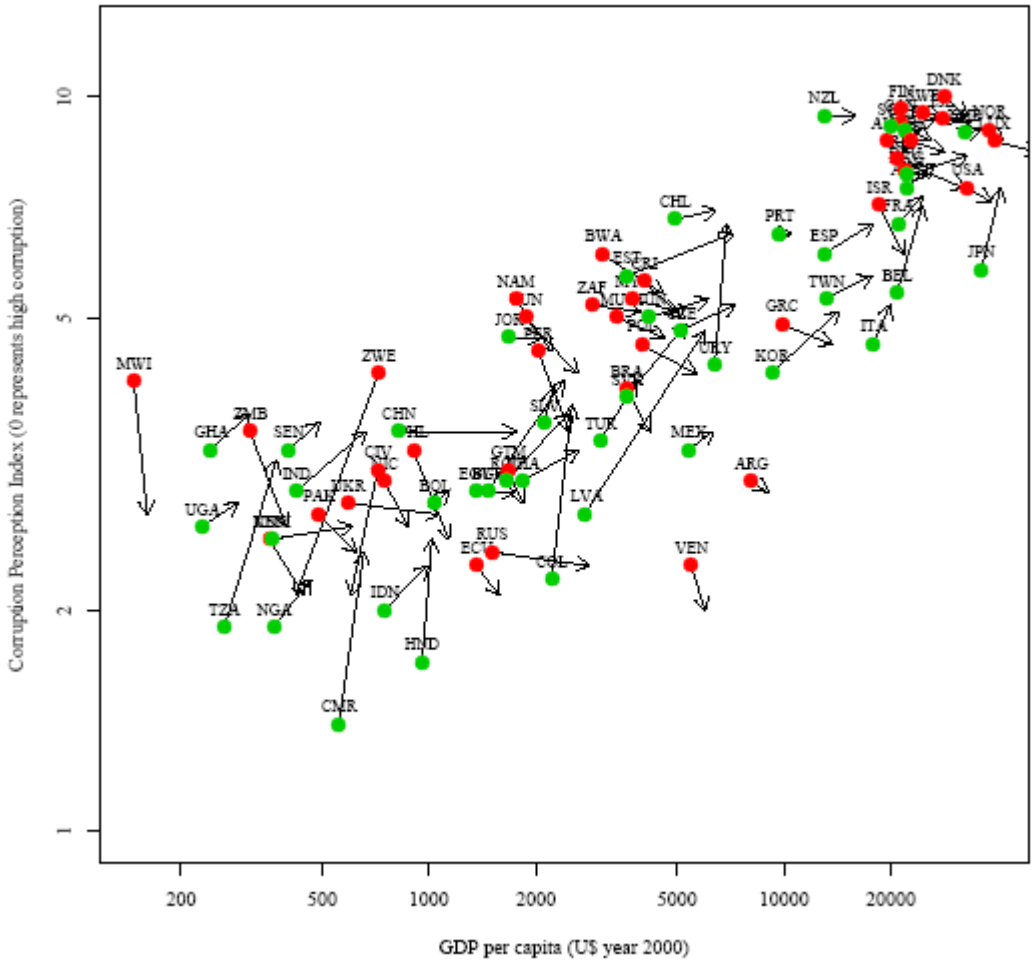

Figure 4.1 Country level CPI and GDP per capita in 1998 (dot) and 2007 (arrow head).

Given the complexity of the bivariate correlations and relationships in Figure 4.1, a cross-lagged longitudinal SEM model will be used to further explore the relationships among changes in both CPI and GDP per capita, and the initial values for both indicators.

4.3 Methodology

Structural Equation Modeling (SEM) is a statistical technique that combines multiple regression and factor analysis. Kline (1998) presents an introductory text, while Tomarken and Waller (2005) review the strengths, limitations and misconceptions of the technique. SEM models are expressed as an *a priori* set of linear equations. SEM is also known as 'covariance structure analysis', reflecting its emphasis on explaining as much of the covariance between the observed variables as possible. Significance tests are generally preformed on the whole of the multi-equation model by testing alternative nested models.

Cross-lagged longitudinal models are a specific class of SEM (Burkholder and Harlow 2003). In the search for causal relations, these models provide the opportunity to test for a time sequence suggesting causality. Cross-lagged longitudinal models also provide the opportunity to test the stability of relationships over time.

In a cross-lagged SEM, unlike traditional regression models, the dependent variable in one equation can be used as an independent variable in another equation. Variables may even be related through reciprocal relationships, each affecting the other either directly or through intermediate variables. This technique has not been used to examine the linkages between corruption and economic growth, though its characteristics make it particularly well suited for the task.

Figures 4.2 and 4.3 illustrate a coefficient and a variance view of a cross-lagged longitudinal SEM model. It contains two measures of interest: one representing development at a country level (D) and the other representing corruption (C) at a country level. Both measures are included as 1) four exogenous variables, representing an initial state measurement and three subsequent increments, and 2) two latent variables representing intermediate state values. By convention, rectangles represent measured variables, ovals represent latent variables and circles represent measurement error on exogenous variables. In the coefficient view (Figure 4.2), the single arrowed lines connecting variables represent regression paths. In the variance view (Figure 4.3), the single arrowed lines connect error components with variables and represent associated variances; the double arrowed lines between error components represent covariances.

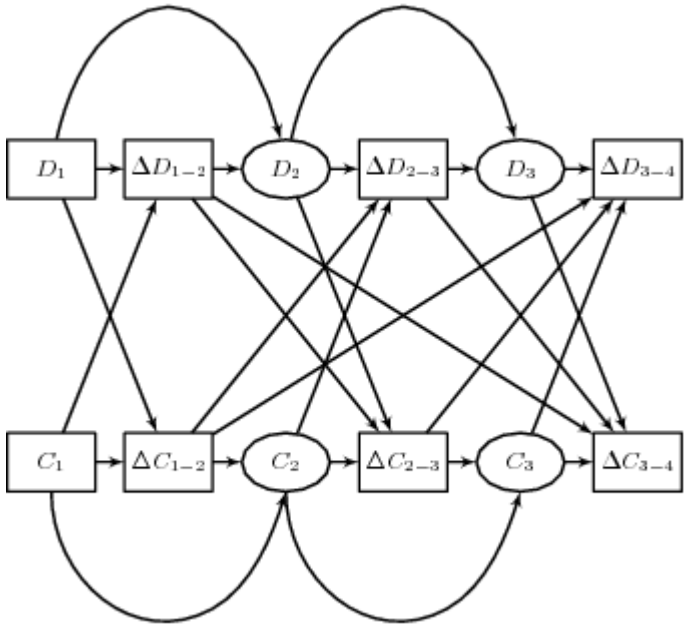

Figure 4.2 A cross-lagged longitudinal SEM model represented by its coefficient view.

The model contains a subset of possible regression paths and variance/covariance effects. Regression paths that imply backwards time effects and implausible covariances have been omitted. The regression paths leading to the latent variables are set to unity reflecting that their values are the simple sum of the prior state variable plus the subsequent increment (i.e., $D_{t+1} = D_t + \Delta D$). They have no disturbance term associated with them, meaning that their error is determined by the contributing variables' errors alone. Thus, these latent variables are identities with known structural parameters and no error variables. They could be substituted out of the model, but are retained for readability.

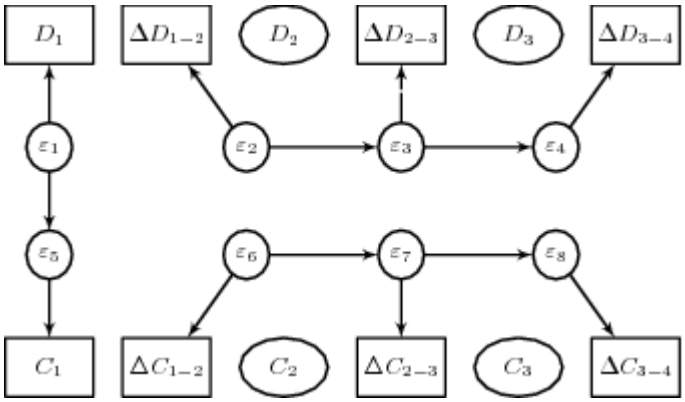

Figure 4.3 A cross-lagged longitudinal SEM model represented by its variance view.

The structure of the cross-lagged longitudinal SEM model allows for a wide range of hypotheses to be tested in examining the corruption/development relationship. The inclusion of both state and increment variables allows the model to represent their possible interactions. The similar structural constructs across time allow for the testing of the stability of parameters through time. The constructs linking more than adjacent time periods allow for the testing of lag effects.

All analyses were done using the Structural Equation Models module (Fox 2002) of the R 2.8.0 statistical package (R 2008). R is also known as `GNU S', a freely available environment for statistical computing, supporting a wide variety of statistical and graphical techniques.

The models were fit with maximum likelihood techniques. The fit was tested against the raw moment matrix rather than the more commonly used standardized moment matrix, because the intercepts were of interest. Chi-square (X^2) and Bayesian information criterion (BIC) are tabulated for each model as fit statistics. Nested models are tested for significant differences using likelihood-ratio tests. The X^2 statistic is related to how well the model replicates the observed covariance matrix. A significant X^2 indicates that the model results are detectably different than the sample. This is not unusual in SEM models and often models are judged on goodness-of-fit indices (Fox 2002). The goodness-of-fit criterion is useful for distinguishing between practically significant differences and statistically identifiable differences. The BIC is one such index. The benchmark just-identified model will have a BIC of 0. A lower BIC value indicates a better and/or more parsimonious model fit. A difference in BIC of 5 is considered strong evidence of a better model, and 10 is conclusive (Raftery 1993).

4.4 Results

Table 4.2 presents the results for the SEM model illustrated in Figures 4.2 and 4.3. In this 'fullest' model, parameter estimates are allowed to vary by period. In the coefficient model, D_1 and C_1 are estimated by simple intercepts. Subsequent values for D and C are calculated as the sums of the previous D or C and an estimated Δ. Each ΔD is estimated from the current levels of

D, C and any previous ΔC. Similarly, each ΔC is estimated by the current levels of D, C and any previous ΔD. The estimated variances and covariances complete the parameter estimates.

Table 4.2 Parameter estimates for the fullest model (bold indicates sig. at P<.05).

	1998				2001		2004	
	D_1	ΔD_{1-2}	C_1	ΔC_{1-2}	ΔD_{2-3}	ΔC_{2-3}	ΔD_{3-4}	ΔC_{3-4}
Coefficients								
Intercept	**8.180**	0.045	**1.489**	**-0.474**	**0.168**	-0.004	**0.136**	**-0.046**
D_n		-0.003		**0.112**	-0.012	0.007	0.004	**0.036**
C_n		0.032		**-0.306**	0.008	-0.062	-0.041	**-0.164**
ΔD_{n-1}						**0.636**		**0.515**
ΔC_{n-1}					0.046		0.012	
ΔD_{n-2}								-0.109
ΔC_{n-2}							0.060	
Var/Cov								
D_n	**2.3752**		**0.6247**					
C_n	**0.6247**		**0.2463**					
ΔX_n		**0.0057**		**0.0218**	**0.0042**	**0.0128**	**0.0039**	**0.0090**
ΔX_{n-1}					**0.0023**	-0.0034	**0.0026**	0.0010

Fit Statistics	X^2	Df	ΔX^2	BIC
	23.38	5	**23.38****	1.5

(Source: author's calculations)

Estimates that are significant at the .05 level of probability are indicated (bold font). Fit statistics for the model as a whole are at the bottom of the table. The significant X^2 indicates that the model results in estimates that are significantly different than the sample. The BIC of 1.5 suggests the model is marginally worse than a just-identified model.

The coefficients that are significant in one period are generally significant in others and maintain their signs. None of the coefficients for estimating the change in development (ΔD) are significant, save the intercept. None of the coefficients involving the 2 period lag variables are significant. The significant coefficients indicate that changes in development are not affected by current development or corruption levels or in recent changes in corruption. In contrast, changes in corruption are affected by current development, corruption and recent changes in development. Reductions in levels of corruption are positively related to both the level of development and recent changes in development. Consistent with the 'convergence' theory, reduction in levels of corruption is negatively related to current levels of corruption.

The bulk of the variance/covariance parameters are significant. The residual variances diminish as more lagged variables are included. The lagged covariances are positive and significant for changes in development but not with changes in corruption.

The results from this 'fullest' model suggest several more parsimonious alternatives. As a first step we will look at collapsing the period differences and test to see if the coefficients are stationary through time.

Table 4.3 Parameter estimates for the time invariant model (bold indicates sig. at P<.05).

	D_1	ΔD_n	C_1	ΔC_n
Coefficients				
Intercept	**8.180**	**0.087432**	**1.489**	**-0.15743**
D_n		0.003157		**0.052607**
C_n		-0.01607		**-0.19658**
ΔD_{n-1}				**0.576609**
ΔC_{n-1}		0.02192		
ΔD_{n-2}				-0.01447
ΔC_{n-2}		0.063147		
Var/Cov				
D_1	**2.375187**		**0.624715**	
C_1	**0.624715**		**0.246276**	
ΔX_1		**0.006439**		**0.025353**
ΔX_2		**0.004821**		**0.013575**
ΔX_3		**0.004417**		**0.009272**
ΔX_{n-1}		**0.002752**		**0.000964**

Fit Statistics	X^2	Df	ΔX^2	BIC
	77.62	21	**54.24****	-14.4

(Source: author's calculations)

Table 4.3 presents the results for a 'time invariant' version of the model. The coefficients have been constrained to be equal across time periods, while the variance/covariance parameters have not. The significant ΔX^2 indicates that the model is statistically detectable as a worse fit than

that of the 'fullest' model. However, the improvement of the BIC from 1.5 to –14.4 indicates it is a much better model. This improvement is due to the reduced number of parameters outweighing the mild worsening of the fit.

As in the previous model, none of the coefficients for estimating the change in development (ΔD) are significant save the intercept. The residual variances are slightly increased by the imposition of time invariant coefficients, but still exhibit the same patterns. These results suggest a yet more parsimonious version, one that only includes an intercept for estimating the change in development.

Table 4.4 presents the results for a 'parsimonious' model. It is time invariant and change in development is estimated by a simple intercept. The insignificant ΔX^2 indicates that the results of this model are not significantly different than the 'time invariant' model discussed above. The decrease of the BIC from the prior –14.4 to –28.0 indicates this form of the model is much better by that measure. The coefficients are essentially the same and a few of the variance/covariance components are slightly elevated. The only insignificant parameter estimates in this model are the coefficient relating the double lagged change in development to a change in corruption and the covariance of the change in corruption with its lagged version.

In the 'parsimonious' model initial development, initial corruption and change in development are all estimated by simple intercepts. Changes in corruption are estimated by development levels, corruption levels, and lagged versions of the change in development. The coefficients for estimating change in corruption indicate reduced corruption levels are related to higher levels of

existing development and positive changes in development, while they are negatively related to lower levels of existing corruption.

Table 4.4 Parameter estimates for the most parsimonious model (bold indicates sig. at P<.05).

	D_1	ΔD_n	C_1	ΔC_n
Coefficients				
Intercept	**8.1797**	**0.0882**	**1.4886**	**-0.1574**
D_n				**0.0526**
C_n				**-0.1966**
ΔD_{n-1}				**0.5766**
ΔC_{n-1}				
ΔD_{n-2}				-0.0145
ΔC_{n-2}				
Var/Cov				
D_1	**2.3752**		**0.6247**	
C_1	**0.6247**		**0.2463**	
ΔX_1		**0.0064**		**0.0254**
ΔX_2		**0.0048**		**0.0136**
ΔX_3		**0.0047**		**0.0093**
ΔX_{n-1}		**0.0028**		0.0010
Fit Statistics	X^2	df	ΔX^2	BIC
	81.58	25	3.96ns	-28.0

(Source: author's calculations)

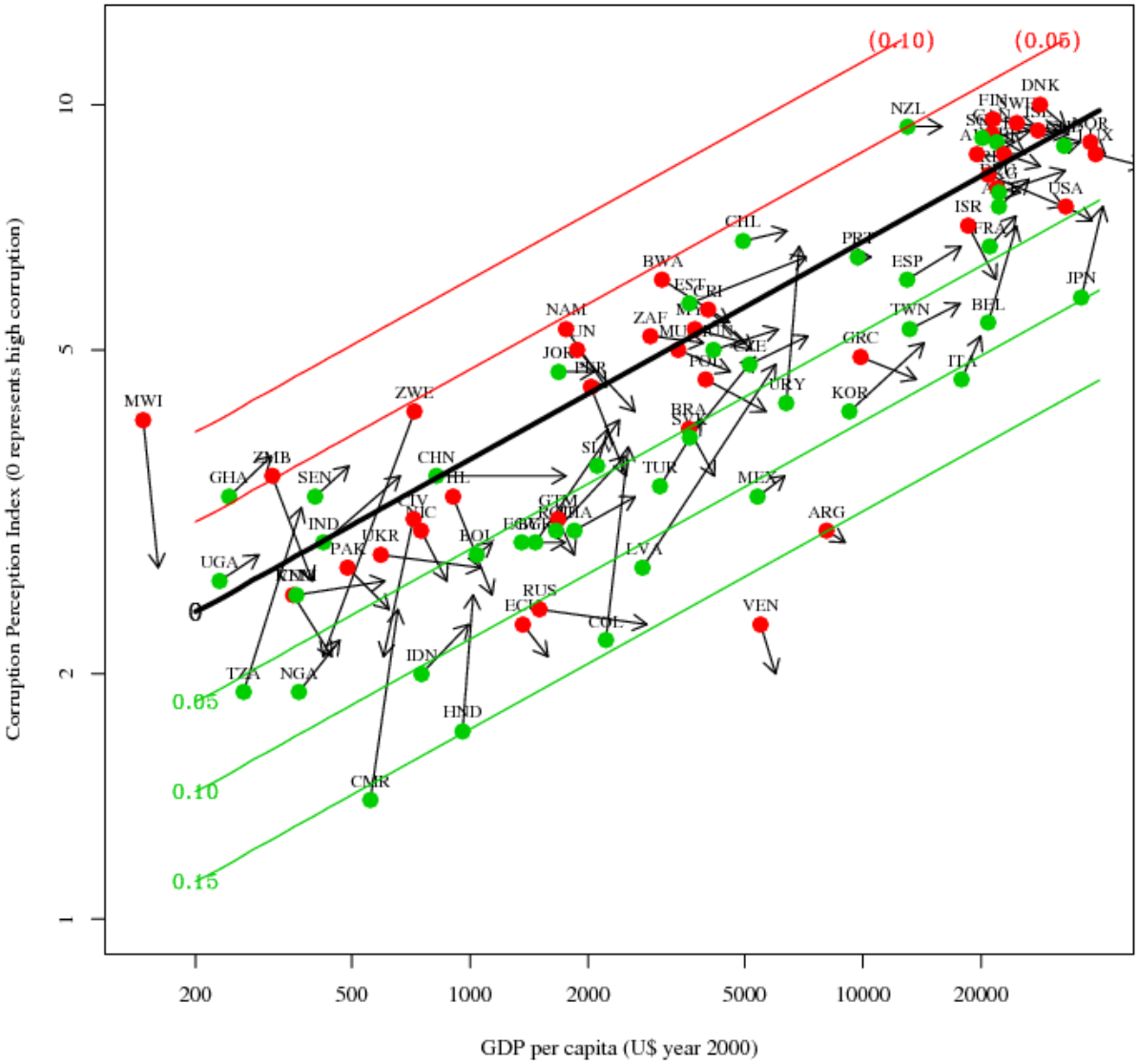

Figure 4.4 Country level CPI and GDP per capita in 1998 (dot) and 2007 (arrow head) with an overlay of the parsimonious model's results for predicting the logarithm of a 3 year CPI change (evaluated at an average GDP per capita growth).

Figure 4.4 further illustrates the results of the 'parsimonious' model. Its predictions for the logarithm of a 3-year change in CPI are overlaid with the same data as used in Figure 4.1. Above the line labeled with a "**0**", CPI is expected to drop in the subsequent period (indicating an increase in corruption); and below the "**0**" line the CPI is expected to increase (indicating a decrease in corruption). These predictions are consistent with the underlying empirical data evidenced by the preponderance of red dots above the "**0**" line and the green dots below.This last model, the parsimonious model, is selected as the final model form. Its BIC indicates that it is the best model and it seems to adequately depict the data.

The final model predicts that Ghana, Malawi, New Zealand, Senegal and Zimbabwe are the five countries from the eighty studied that are likely to have the worst percentage change in CPI in the period from 2008 to 2010. The five predicted to improve the most are Argentina, China, Latvia, Russian Federation and Venezuela.

4.5 Conclusions

This paper made use of a cross-lagged structural equation model (SEM) to find empirical evidence on both the existence and direction of the cause-effect linkages between corruption and development. Unlike traditional regression analysis, SEM can directly estimate models where variables have reciprocal relationships. The cross-lagged model tests for conditions that suggest cause-effect relationships.

The results for a series of nested models were presented and a 'best' model identified. The 'best' model indicates a cause-effect linkage between increased GDP per capita and subsequent

reductions in corruption; but no cause-effect linkage was found between reduced corruption and subsequent increases in GDP per capita.

The GDP per capita/CPI linkage has an additional dimension. There is a tendency for countries to attain a 'normal' level of corruption, for any given level of development. For example, Botswana (BWA) experienced an increase in corruption (1998-2007) despite an increase in GDP per capita. This is consistent with model predictions as BWA had, initially, a surprisingly low level of corruption for its level of development.

The general results of the study have policy implications:

1) An increase in economic development should lead to a reduction in corruption. However, some countries are in danger of regressing to a state of greater corruption, as they tend towards the norm for their particular level of development.

2) A reduction in corruption is not sufficient, in itself, to lead to an increase in development. Thus, there is no support for the 'virtuous cycle': a cycle where reduced corruption leads to increased economic development, which then leads to yet a further reduction in corruption, *ad infinitum*.

Further empirical work could identify how different elements (e.g. components of the human development index) of economic development, defined only as GDP per capita in this paper, affect corruption. The objective of this further work would be to find broader set of public policies to reduce corruption.

5 Illegal Logging in Forest Sector Trade Models: The Inclusion of Corruption[15]

5.1 Introduction

Illegal logging results in an annual loss of U$10 billion in assets and U$5 billion dollars in taxes in the countries where it occurs (World Bank 2006). It also discourages investment, discourages improved logging practices, undermines the rule of law and exacerbates wealth disparities in those countries (Kaimowitz 2003). It can affect the rural livelihoods of the 735 million people who live in or near closed tropical forests, depending on them for many of their needs (Contreras-Hermosilla et al. 2007).

Illegal logging also has global effects through its impact on ecosystem services. It can lead to reductions in biodiversity and water quality, while contributing to erosion and flooding (Waggener 2001). Through its effects on global carbon stocks, illegal logging can also contribute to global warming (Contreras-Hermosilla et al. 2007).

Globally, illegal logging is estimated to be 10% of the forest products traded (Brack 2003). A large number of countries are involved as suppliers including all tropical countries, plus Russia and China. The buyers include countries in the European Union, China, Japan and the United States (Contreras-Hermosilla et al. 2007).

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15 A version of Chapter 5 will be submitted for publication. Northway, S. and G.Q. Bull. Illegal Logging in Forest Sector Trade Models: The Inclusion of Corruption.

To assess the extent of the problem, we commonly use global forest trade models to predict the prevalence and distribution of illegal logs and their products (Senica 2004; Northway and Bull 2006; Turner et al. 2007; Li et al. 2008; Moiseyev et al. 2010). In these models, an estimate of illegal logging over time defines the baseline (or base case) and then the effects of illegal logging are measured against this baseline.

We draw a distinction between illegal logging and the corruption that enables it. Illegal logging comprises harvesting without proper authority, harvesting in excess of approved limits, failing to report harvest activity in order to avoid royalties, and/or trade in forest products in violation of international agreements (Seneca 2004). Corruption, on the other hand, is the abuse of public office for private gain (World Bank 1997). We recognize that reducing corruption is only part of the solution for eliminating illegal logging. Illegal logging, where it remains undetected, could still occur in the absence of corruption (Callister 1999).

The purpose of our paper is to: 1) examine the commonly used assumptions behind estimates of baseline trends of illegal logging in trade modeling, 2) appraise the feasibility of using predicted trends in corruption as a basis for estimating baseline trends in illegal logging, and 3) evaluate the hypothesis that corruption based estimates of illegal logging trends result in more appropriate estimates of policy results.

5.2 Background

Global forest trade models were first applied to the question of illegal logging by Seneca (2004) using the Global Forest Products Model (GFPM) (Buongiorno et al. 2003). The Seneca (2004) study looked at the impact of illegal logging on the United States forest products industry. The

GFPM has also been used to look at the impact of illegal logging on the New Zealand forest products sector (Turner et al. 2007), and at the effect of a slow reduction of illegal logging on the global forest sector (Li et al. 2008). In each of these studies a country's total log supply is represented by an econometric supply curve. The baseline illegal logging was estimated as a constant proportion of each country's total log production. The proportion of illegal logging was considered fixed for the duration of the analysis period.

The European Forestry Institute's Global Trade Model (EFI-GTM) (Kallio et al. 2004) has been used to test the impact of European Union policy measures to curb illegal logging on global trade (Moiseyev et al. 2010). As in the previously mentioned studies, a country's total log supply is represented by an econometric supply curve. The baseline illegal logging was estimated as a static proportion of each country's total log production. The proportion of illegal logging was considered fixed for the duration of the analysis period

The International Forest and Forest Product Model (IFFP) (Northway and Bull 2006) was used to look at the efficacy of bilateral trade agreements on the trade of illegal forest products between Indonesia and China (Northway and Bull 2006). In this study, legal and illegal logging were represented as separate processes. As distinct from the previously mentioned studies, the IFFP included a forest estate model within the trade model. Illegal and legal logging take place on overlapping land bases with distinct costs and capacities. However, in a similar manner to the previous studies the illegal logging costs and capacities were fixed over the duration of the analysis period.

5.3 Methods

5.3.1 Linking corruption and illegal logging

By its very nature, figures on illegal activities are difficult to compile. Discrepancies in government-collected statistics are often used to infer illegal sources of forest products. While there are other motives and explanations for the discrepancies, researchers in the field still feel that illegal activities are a significant source of discrepancies in the statistics (Goetzl 2005).

Seneca (2004) combined bilateral trade data from the Global Trade Information System with country level harvesting and manufacturing to develop country-level wood balances. This balance may show the reported harvest, combined with imports and exports, as insufficient to support the level of manufacturing reported. In this case, the unexplained deficit of reported logs could be inferred as coming from illegal logging (Seneca 2004).

Transparency International's Corruption Perception Index (CPI) is used as an indication of country wide corruption (TI, 2010). The CPI is based on surveys of experts and businesses and their perception of corruption in the public officials and politicians of a particular country. The index ranges from 0 to 10, with 0 indicating a high level of 'perceived' corruption.

Figure 5.1 illustrates the link between corruption and suspected illegal logging for a number of countries or country groups (Seneca 2004). Higher levels of estimated illegal logging are associated with higher levels of corruption, as measured by the CPI. Indonesia is the extreme data point in Figure 5.1 with the highest level of illegal logging and the highest level of corruption (lowest CPI). Figure 5.1 suggests that if a country becomes less corrupt over time,

illegal logging should abate.

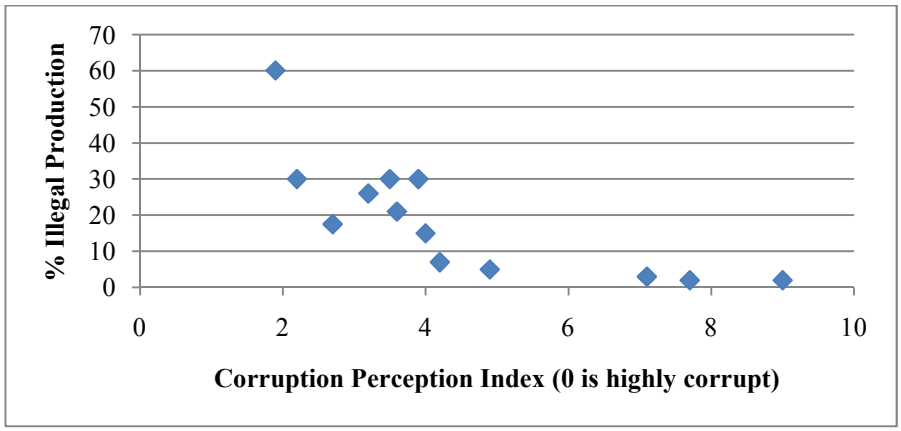

Figure 5.1 Corruption and illegal logging estimates for 2002 (Seneca 2004)

In examining the development of corruption, Northway and Bull (2011) found a causal relationship between changes in GDP per capita and changes in corruption (Chapter 4). To illustrate the relationship between GDP per capita, CPI and illegal logging we chose to present Indonesia up to the year 2025 (Table 5.1). The projected GDP per capita, expressed in nominal year 2000 $US, come from the USDA Economic Research Service (USDA, 2008). The projected CPI estimates come from the recursive application of the relationship found in Northway and Bull (2011) (Chapter 4). The

Table 5.1 Indonesia's projected development in wealth, corruption and illegal logging.

Year	GDP/ Capita (U$)	CPI	Illegal Logging (% total)
2002	$1,166	1.9	67
2005	$1,305	2.2	60
2010	$1,483	2.8	47
2015	$1,811	3.1	41
2020	$2,210	3.5	32
2025	$2,709	3.9	24

(Source: author's calculations)

projected % Illegal logging estimates come from the link implied in Figure 5.1 between the projected CPI and % Illegal logging.

There is no reason to expect that the % Illegal logging in Indonesia should remain static. The anticipated growth in GDP per capita should lead to a general reduction in corruption, which, in turn, will be reflected in lower levels of illegal logging. Table 5.1 indicates that in the absence of outside influences, the level of illegal logging should drop from an estimated 60% in 2002 to 24% by 2025.

5.3.2 Trade model

The trade model, upon which we ran the experiments, is based on the IFFP[16] model described in Northway and Bull (2006) and Northway and Bull (2009). The basic supply of logs comes from an imbedded forest estate model in each country. The model represents 13 products including non-forest based fibres, recycled paper, saw logs, pulp logs, poles, chips, pulp, sawn wood, plywood, panels, news print, packaging and writing paper. The products are linked by 12 processes, in addition to the logging processes, representing manufacturing steps. Three regions are represented in this version of the model: Indonesia, China and the Rest-of-the World. The model develops projections for five year steps from 2005 to 2025. The original model has been augmented with Armington Elasticities (AE) (Armington 1969) for China's imports of packaging and Indonesia's imports of pulp using the methodology outlined in Northway et al. (2011) (Chapter 3).

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[16] A copy of the software is available from the corresponding author.

The IFFP has a separate forest estate model for legal and illegal logging, utilizing overlapping land bases (BAPPENAS 2005). The effect of reduced illegal logging was implemented by exogenously reducing the capacity for illegal logging in proportion to the reduction estimated in the previous section of this paper. This was the model used to test the implications of replacing a static illegal logging baseline with a dynamic illegal logging baseline.

5.3.3 Illegal logging scenarios

We utilize three scenarios to estimate the impact of illegal logging on Indonesia's forest industry. Two scenarios represent the alternative views of the base-line development of illegal logging over time and the third represents the immediate cessation of illegal logging.

5.4 Results

Table 5.2 summarizes the % illegal logging that occurs under the three different scenarios. Under the 'No Illegal Logging' scenario, no illegal logging takes place. Under the commonly assumed 'Static Illegal Base' scenario, the results fluctuate with around 60% of the logging coming from illegal sources. In the 'Dynamic Illegal Base' scenario, illegal logging starts in 2005 as 56% of the total and drops to 35% by 2025 as the general level of corruption abates. (This differs from the figures in Table 5.1 in reflecting concomitant changes in the global forest

Table 5.2 Scenario results for illegal logging as a % of total to 2025

Year	No Illegal Logging	Static Illegal Base	Dynamic Illegal Base
2005	0%	59%	56%
2010	0%	61%	49%
2015	0%	62%	46%
2020	0%	63%	39%
2025	0%	60%	35%

(Source: author's calculations)

sector.) Clearly, incorporating the effects of GDP per capita and corruption levels has a dramatic effect on the estimated percent of production that is associated with illegal logging activities: the difference between 60% and 35% in 2025.

Following from Table 5.2, Table 5.3 provides a more detailed description of the projected 2025 status for the production, import, export and local price of components of Indonesia's forest sector under the two scenarios that include illegal logging. These are the alternate base cases of the 'Static Illegal Base' scenario and the newly herein suggested 'Dynamic Illegal Base' scenario. The 'Static Illegal Base' scenario reflects the usual assumption of illegal logging as a constant proportion of the total amount of logging. The 'Dynamic Illegal Base' scenario estimate is based on linking the propensity for illegal logging to the expected changes in the general level of corruption.

Table 5.3 Indonesia's forest sector in 2025 under alternative illegal logging scenarios

Product	Static Illegal Base				Dynamic Illegal Base			
	Production (mil. m3 or ton)	Imports (mil. m3 or ton)	Exports (mil. m3 or ton)	Price ($/m3 or $/ton)	Production (mil. m3 or ton)	Imports (mil. m3 or ton)	Exports (mil. m3 or ton)	Price ($/m3 or $/ton)
Roundwood	208	0	0	66.37	145	7	0	71.78
Sawnwood	0	9	0	153.90	0	9	0	153.90
Wood panels	33	0	16	342.21	30	1	13	343.09
Wood pulp	59	15	14	393.48	45	15	0	394.88
Paper	66	0	22	1498.08	66	0	22	1498.96

(Source: author's calculations)

Table 5.3 depicts the roundwood production under the 'Static Illegal Base' at 208 million m3, higher than that under the 'Dynamic Illegal Base' at 145 million m3 (even after being augmented with 7 million m3 of imports). The extra production of illegal roundwood in the 'Static Illegal Base' depresses the local price to $66.37/m3 compared to the $71.78 for the 'Dynamic Illegal Base'. While paper production differs little between the alternative illegal bases; the production of wood pulp is significantly lower under the 'Dynamic Illegal Base', resulting in reduced exports. Clearly, these are quite different baselines from which to test the impact of eliminating illegal logging.

Following from Table 5.3, Table 5.4 illustrates the projected 2025 status for the production, import, export and local price of components of Indonesia's forest sector under the 'No Illegal Logging' scenario. The differences between this scenario and the scenarios that include illegal logging estimate the impact of eliminating illegal logging.

Table 5.5 illustrates the impacts of eliminating illegal logging as estimated as the difference of the two alternate bases (Table 5.3) and the 'No Illegal Logging' scenario (Table 5.4). The most striking result is in the production of roundwood.

Table 5.4 Results in the absence of illegal logging for Indonesia's forest sector 2025

Product	No Illegal Logging			
	Production (mil. m3 or ton)	Imports (mil. m3 or ton)	Exports (mil. m3 or ton)	Price ($/m3 or $/ton)
Roundwood	154	30	0	73.78
Sawnwood	0	9	0	154.14
Wood panels	30	1	14	343.28
Wood pulp	45	15	0	397.39
Paper	66	0	22	1499.57

(Source: author's calculations)

Eliminating illegal logging from the 'Static Illegal Base' is expected to decrease roundwood production by 53 million m3; while eliminating illegal logging from the 'Dynamic Illegal Base' is expected to result in an increase in roundwood production by 9 million m3. This happens as the induced increase in the domestic price, through the elimination of illegal logging, leads to greater stimulation in legal harvest than is lost in illegal harvest. Other measures of the impact of eliminating illegal logging are also more appealing from the 'Dynamic Illegal Base'. The

Table 5.5 Scenario results for illegal logging in Indonesia's forest sector 2025

Product	Static Illegal Base				Dynamic Illegal Base			
	Production (mil. m3 or ton)	Imports (mil. m3 or ton)	Exports (mil. m3 or ton)	Price ($/m3 or $/ton)	Production (mil. m3 or ton)	Imports (mil. m3 or ton)	Exports (mil. m3 or ton)	Price ($/m3 or $/ton)
Roundwood	-53	30	-	7.41	9	23	-	2.00
Sawnwood	-	-	-	0.24	-	-	-	0.24
Wood panels	-4	1	-2	1.07	-0	1	0	0.19
Wood pulp	-14	-	-14	3.91	-	-	-	2.51
Paper	-	-	-	1.49	-	-	-	0.61

(Source: author's calculations)

expected loss of export earnings found under the 'Static Illegal Base' is not expected under the 'Dynamic Illegal Base'. The increases of domestic prices are less under the 'Dynamic Illegal Base'. This example illustrates that the differences in conclusions resulting from the two the baseline scenarios can be not just a matter of degree, but rather one of direction.

5.6 Conclusions

The use of the usual 'Static Illegal Base' leads to unrealistic estimates of the medium and long-term effects the elimination of illegal logging. A 'Dynamic Illegal Base' that incorporates the expected changes in illegal logging that follows the general reduction in a country's corruption is a more realistic baseline.

In the example presented the conclusions of the impacts of eliminating illegal logging were not just different by a matter of degree, but in the case of roundwood production reversed the conclusion as to whether it would increase or decrease with the elimination of illegal logging. The 'Static Illegal Base' makes the estimated effects of eliminating illegal logging appear more forbidding in terms of effects on domestic prices and export earnings, perhaps at the cost of leading to hesitancy in acting on illegal logging. The more realistic 'Dynamic Illegal Base' shows a more muted cost of acting against illegal logging.

6 CONCLUSION

6.1 Overview and Chapter Linkages

In this dissertation, I have outlined three improvements to the standard forest products trade model. The four manuscript chapters (Chapters 2-5) present both the theoretic rational and examples of the impact of using each improvement. Chapter 2 demonstrates the merits of replacing a constant with variable marginal manufacturing costs. Chapter 3 argues that trade inertia should be replaced with Armington elasticities. Chapter 4 evaluates the relationship between a country's development and corruption. Chapter 5 builds on Chapters 2-4 by implementing their improvements in the analysis of a case study on the impacts of illegal logging.

The standard form of the forest products trade model presented in the Introduction (Chapter 1) can now be updated with the improvements presented in the intervening chapters. Equation [6.1], the material balance constraint found in the standard model remains unchanged:

$$S_{ik} + \sum_{j} T_{jik} + \sum_{n} Y_{ikn} \geq D_{ik} + \sum_{j} T_{ijk} + \sum_{n} a_{ikn} * Y_{ikn} \qquad \forall\, i, k \qquad [6.1]$$

where i,j=regions, k=products, n=processes, S=supply, T=trade, Y=manufacturing process, D=demand, and a=conversion efficiency. There must be more product available within a region than is dispersed.

Equation [6.2] is minimized to solve the standard model (making use of Samuelson's (1952) observation):

$$\sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})\ \delta D_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik})\ \delta S_{ik}$$

$$- \sum_i \sum_j \sum_k c_{ijk} * T_{ijk} - \sum_i \sum_k \sum_n m_{ikn} * Y_{ikn} \qquad [6.2]$$

where P=price, c=transport cost and m=manufacturing cost. But the analysis in Chapter 2 suggests that the fourth element of this expression, the constant manufacturing cost (m_{ikn}) would be better replaced with a function representing a variable cost as in equation [6.3].

$$\sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})\ \delta D_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik})\ \delta S_{ik}$$

$$- \sum_i \sum_j \sum_k c_{ijk} * T_{ijk} - \sum_i \sum_k \sum_n \int_0^{Y_{ikn}} P_{ikn}(Y_{ikn})\ \delta Y_{ikn} \qquad [6.3]$$

This expression obviates the need for the upper limit on manufacturing capacity found in the standard model; regional manufacturing will be limited by an increasing cost and concomitant reduction in competitiveness in the global market place.

As seen in Chapter 3, this switch to a variable manufacturing cost greatly improves model behavior and mitigates some of the behavior that otherwise requires the trade inertia constraints found in the standard model. Whatever the expressed motivation for trade inertia, it has the effect of enforcing reasonable country level manufacturing levels in the absence of a reasonable manufacturing cost expression. The variable marginal manufacturing cost allows a properly

calibrated model to replicate a country's manufacturing levels without the use of trade inertia constraints.

Still, some additional efforts are required to enable the model to replicate observed trading behavior. *Cross hauling*, where a region imports and exports the same product, is problematic to trade modelers. The standard trade model is based on replicating the actions of rational agents. A rational agent would see in *cross hauling* an opportunity for arbitrage, pocketing the savings from the unnecessary trading costs. Yet *cross hauling* shows up in the trade statistics to which trade models are calibrated and in situations they are meant to reflect.

Chapter 3 examined *cross hauling* and suggested that the idiosyncratic use of trade inertia in the standard forest product trade model be replaced with the more broadly embraced use of Armington elasticities (Armington, 1969). Equations [6.4] and [6.5] represent the trade inertia constraints found in the stand forest products trade models.

$$T_{ijk} \leq T_{ijk}^{U} \qquad \forall\, i,j,k \qquad [6.4]$$

$$T_{ijk} \geq T_{ijk}^{L} \qquad \forall\, i,j,k \qquad [6.5]$$

where T^U=upper limit of trade and T^L=lower limit of trade. Note that these are absolute limits, and are independent of changes in product price or demand. Equations [6.6] and [6.7] contain the changes tested in Chapter 3.

$$T_{ijk}/D_{ijk} \leq T_{ijk}^{U} \qquad \forall\, i,j,k \qquad [6.6]$$

$$T_{ijk}/D_{ijk} \geq T^{L}_{ijk} \qquad \forall\, i,j,k \qquad [6.7]$$

These changes only go part way to implementing Armington elasticities. They ensure that the imports of a product relative to its regional consumption remain within a specified range. This constraint enables *cross hauling* in suitable circumstances.

Armington elasticities also allows for the substitution between the imported and domestic version of the product. This substitution is driven by changes in the relative prices from that found in the calibration data set. As suggested in Chapter 3 and implemented in Chapter 5, this second effect of Armington elasticities can be implemented by modeling the 'demand' version of the product as a composite good made up of the imported and domestically produced version. The substitution options can then be represented by a set of alternative processes which produce composite goods from a variety of proportions of imported and domestic product. The relative costs of the alternative processes reflect the desired elasticities.

Chapters 4 and 5 are concerned with improving the representation of *status quo* illegal logging found in the standard forest product trade model. Chapter 4 presents the background necessary to project changes in corruption, from changes in development, that are then used in Chapter 5 to project changes in the *status quo* level of illegal logging.

Chapter 4 contributes to the search for evidence for the direction of causal effects between corruption and development by looking at panel data with a structural equation model. The results indicate a positive causal link from changes in development to changes in corruption, but

no causal link in the other direction. This relationship can make use of exogenously projected changes in a country's development to project changes in its level of corruption.

Chapter 5 presents an improved analysis of illegal logging impacts by combining the variable cost manufacturing component found in Chapter 2, with the Armington elasticities found in Chapter 3 and the corruption projections found in Chapter 4. In the case examined, the standard forest products trade model overstated the medium term impact of illegal logging. While the standard analysis suggested eliminating illegal logging would have considerable effects on export earnings and domestic prices, the improved analysis provided a case for eliminating illegal logging.

This dissertation presents three improvements to the standard forest products trade model. Implementing these improvements will result in more accurate estimates of sectoral activity and trade. These improvements will lead to better policy creation, implementation and evaluation.

6.2 Limitations

The limitation of this modeling structure is in the use of Samuelson's (1952) suggested optimizations as a way to solve for the activities of rational agents. The approach fails when trying to directly represent elasticity of substitution in demand (Takayama and Judge 1971).

6.3 Future Research

An agent based approach to solving trade models should be explored as a replacement for utilizing Samuelson's solution. The agent based approach could be used to extend existing models to represent elasticity of substitution in demand. An agent based approach would also

have the advantage of being able to mimic non-rational, but nonetheless realistic, agents such as exist in monopolistic and controlled markets.

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