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Sustainable Energy Crops: An Analysis of Ethanol Production from Cassava in Thailand

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SUSTAINABLE ENERGY CROP: AN ANALYSIS OF ETHANOL PRODUCTION

FROM CASSAVA IN THAILAND

by

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ABSTRACT

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The first essay formulates a dynamic general equilibrium optimal control model of an energy crop as part of a country's planned resource use over a period of time. The model attempts to allocate consumption, production, and factors of production to achieve the country's sustainable development goal. A Cobb-Douglas specification is used for both utility and production functions in the model. We calibrate the model with Thailand data. The selected model is used to generate the stationary state solution and to simulate the optimal policy function and optimal time paths. Two methods are used: a linear approximation method and the Runke-Kutta reverse shooting method. The model provides numerical results that can be used as information for decision makers and stakeholders to devise an economic plan to achieve sustainable development goals.

The second essay studies the effect of international trade and changes in labor supply, land supply, and the price of imported energy on energy crop production for bio fuel and food, as well as impacts on social welfare. We develop a dynamic general equilibrium model to describe two baseline scenarios, a closed economy and an open economy. We find that international trade increases welfare and decreases the energy price. Furthermore, resources are allocated to produce more food under the open economy scenario than the quantities produced under a closed economy assumption. An increase in labor supply and land supply result in an increase in social welfare. An increase in imported energy price leads to a welfare loss, higher energy production, and lower food production.

The third essay develops a partial equilibrium econometric model to project the impacts of an increase in ethanol production on the Thai agriculture sector over the next ten years. The model is applied to three scenarios for analyzing the effect of government ethanol production targets. The results from the baseline model and scenario analysis indicate that an expansion in ethanol production will result in a significant increase in cassava production, price, and land use. The increase in cassava production will shift land use from maize and sugar cane, thus increasing in price of maize.

(150 pages)

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INTRODUCTION

This dissertation focuses on the “competition” between food and fuel uses for energy crops. Production of bio fuels from energy crops can provides clean energy in many countries. It has advantages in generating income, creating employment, and reducing energy import dependence. In contrast, the production of energy crops can also have negative effects, particularly on food consumers and agricultural markets. The production of bio fuel crops requires resources that may also be used for food production, as land, water, labor, and other resources are allocated away from food production to produce fuel. The additional demands for energy production can cause the prices of agricultural products to rise and the structure of agricultural sector to change. Thus, the development and increase in bio fuel production requires a careful plan that addresses the broader impacts of bio fuel production, namely the conflict between food and fuel.

The first essay relates to energy crop planning. This essay develops a dynamic general equilibrium optimal control model of an energy crop to be grown in Thailand. The objective of the model is to plan a country’s resource use over a period of time to achieve a sustainable path of development. The model describes the optimal level of consumption, production, and allocation of resources in the economy. Thailand data are employed in calibration the model, with a focus on cassava as an energy crop. The second essay is an extension study of first essay. The dynamic general equilibrium model of energy crop from the first essay is extended to study the effect of international trade and how changes in land supply, labor supply, and imported energy price affect energy crop production for fuel and food, as well as the effect on welfare. The third essay gauges the impact of ethanol production on the Thai agricultural sector by developing a partial equilibrium econometric model to forecast the equilibrium quantities, prices, and land use of cassava, maize, and sugar cane (which are competing crops). The econometric model is used to analyze the impacts of the Thai government's ethanol expansion program over the next 10 years.

ESSAY 1: ENERGY CROP PLANNING FOR SUSTAINABLE DEVELPMENT

Introduction

The emergence of ethanol production for bio-fuel leads to the dilemma regarding the ‘food or fuel’ issue. This is because most bio-energy, particularly ethanol, is currently produced from a variety of food crops, or so called ‘energy crops’, such as corn, sugar cane, cassava, sweet sorghum etc. In addition, the large scale production of energy crops to supply bio-fuel production uses the same land and resources as those used for food production. This affects food availability if food and fuel production are integrated and produced from the same resources.

The global production of ethanol has increased more than fourfold between 2000 and 2008, where the United States currently produces more than 50% of global production and Brazil produces about 37% of global production (RFA, Renewable Fuels Association, 2010). A significant increase in ethanol production implies a significant increase in land and resources use. It competes with food production. Moreover the use of food crops to supply bio-energy has directly affected an increase in food prices. The issue of the conflict between food and fuel is a serious problem for all countries in the world. The allocation of a country’s resources to produce food or bio-fuel needs to be responsibly planned in order to balance to achieve the food security of the nations. In this study, the concept of sustainable development will focus only on the food security issue and how it affects the balance of food and energy across generations to achieve a sustainable goal.

As ethanol production has increased its share of food crop production there by affecting the food security of a country, concern has developed relative to consumption, production, and allocation of resources of that country. The current study will attempt to determine the optimum of consumption, production and allocation of resources in the economy based on the conflict between food and energy production. The purpose of the study is to plan a country's resources over a period of time to produce an energy crop to achieve a sustainable development goal.

The study will develop a dynamic general equilibrium model to describe the consumption, production, and allocation of resources in the economy. The model is analyzed in a continuous time optimal control framework. It is calibrated to the Thai economy and highlights cassava as an energy crop. Thailand is sixth in ethanol production in the global bio-fuel context only four years after starting domestic production (F.O. Licht, 2008). As it a low-income country that suffers from high food prices, it is interesting as a new small country with a high potential in developing energy crops for bio-fuel. Moreover, the Thai government set the issue of bio-fuel production as a national agenda. This implies that bio-fuel in Thailand is a very important issue and all stakeholders in the economy have to be concerned.

The next section provides the literature review. In section III, the dynamic general equilibrium model of food and energy is developed for the Thai economy. In section IV, the empirical model is derived following the dynamic general equilibrium model. In section V, the model is calibrated using Thailand data to allocate all factors in production, and consumption. Section VI is the conclusion.

Literature Review

There have been several studies relating ethanol production and sustainable development. The UN-Energy (2007) published a framework for decision makers in bio-energy. The framework provides nine key sustainable issues and describes the approaches to current decisions involved in bio-energy. The nine key sustainability issues areas follow: (1) The ability of modern bio-energy to provide energy service for the poor; (2) Implications for agro-industrial development and job creation; (3) Health and gender implication; (4) Implications for the structure of agriculture; (5) Implications for food security; (6) Implications for government budgets; (7) Implications for trade, foreign exchange balances, and energy security; (8) Impacts on biodiversity and natural resource management; and (9) Implication for climate change. The framework of the implication on food security is addressed in three issues: (1) an analytical framework for food and bio-energy needs to developed for understanding the long-term impacts of bio-energy expansion on country; (2) research direction should aim to improve agricultural resources to increase overall output in a sustainable manner for lessening the tension between food and fuel; and (3) policy makers should integrate and develop policies relating to the impacts and inter-impacts of relevant policies at different levels. The direction and implication used in the United Nations framework is applied to this study. The goal of this study is to examine long term impacts and sustainability.

Godemberg, Teixeira, and Guardabassi (2008) studied the sustainability of ethanol production from sugar cane. Their study focused on the Brazilian sugar cane industry by analyzing the impacts of sugar cane ethanol production on two aspects. The environmental aspect was analyzed based on air quality, water availability and pollution, land use, and biodiversity. The social aspect was analyzed on social impacts, jobs, wage, income distribution, ownership, and working conditions. They found that the expansion of sugarcane for ethanol reduced pollution but affected the biodiversity area, deforestation, soil damaging, water contamination and decreasing food security of the country.

Amaro, Jeferson, Ricado, and Renato (2007) analyzed the energy sector in Brazil by using energy indicator for sustainable development of the National Energy Outlook 2030. The study analyzed the energy indicator on three aspects: social, economic, and environmental. They found that on economic aspects, Brazil has an efficient ethanol production, long term consumption close to the indicator pattern, a high availability of resources, and a low dependence on energy import. The environmental aspect had good results. However, the social aspect revealed that a large part of the population is unable to afford modern forms of energy. They concluded that the inequality of income distribution is the key obstacle preventing Brazil from achieving a sustainable development goal.

Sagar and Kartha (2007) found that sustainable development lies in the policy decisions made on how bio-fuel feedstock is produced and marketed. Sustainability is affected by several factors: agriculture sector trend is towards a large scale from the growth of bio-fuel; agriculture subsidies distort the agriculture markets and commodity prices; the lack of agro-processing ability makes it difficult for farmers to get a return from their product; and food security issues have been serious and unanticipated effects.

Dynamic optimal control is the main methodology in the current study. The method formulates the general equilibrium of energy crop production and international trade. Some previous studies on energy crop production were conducted with dynamic optimization. Chakravorty, Magné, and Moreaux (2008) studied the allocation of land to produce ethanol from corn (mixed with gasoline) to meet the clean air standards. The authors extended the Hotelling model to consider clean fuel to substitute for fossil fuel. The utility function of an economy at any given time of their study is an additive utility function of food and energy. The model has two primary factors to allocate, land and fossil fuel. An allocation on land affects the portion of farming to produce food and energy. An allocation on energy affects the farming fuel production and fossil fuel extraction. The fuel from land farming and fossil extraction are assumed to be a perfect substitution. Chen, Khanna, and Önal (2009) evaluated the economic potential of bio-fuel in the dynamic land use model. They assumed imperfect substitution between ethanol and gasoline. The utility of economy is the sum of utility from miles driven and food consumed. The model maximizes the choice between fuel and food production by constraining both the CES (Constant Elasticity of Substitution) production function and the land use.

In the current study, the dynamic optimization model differs from previous studies. The model applies dynamic general equilibrium optimal control that maximizes utility (composed of the composite commodity and food). The primary factors in production are capital, labor, land, and energy. The production functions are specified as

Cobb-Douglas functions. The model assumes that ethanol and fossil energy are perfect substitutes.

In the current study, cassava is one among a variety of energy crops in Thailand selected to be used as a feedstock for ethanol production. Several studies have indicated that cassava in Thailand has a potential for ethanol production because it costs less to refine and has a higher cultivation than sugar cane. Sriroth, Lamchaiyaphum, and Piyachomkwan (2000) studied the present situation and future potential of cassava in Thailand. Their study found that the total area of cassava production was stable, even as the yield was improving.

In a similar way, Nguyen and Gheewala (2008) studied cassava-based gasoline in Thailand by focusing on comparing between fossil energy and the alternative ethanol energy. The study found that ethanol in Thailand was fermented from molasses. However, molasses production would not meet the government ethanol target. In contrast to molasses, cassava is a high potential supply crop and has a lower cost for the ethanol industry. The Thai government supports the research and development of cassava on a pilot scale production of ethanol, especially in biochemical and chemical engineering. Papong and Malakul (2009) conducted a study on bio-ethanol production from cassava in Thailand by covering the crop’s lifecycle: cultivating, processing, transportation, and ethanol conversion. The study founded that 12 cassava-based ethanol producers had registered with Thailand authorities and the 12 producers reported a capacity of 2.53 million liters per day. The study concluded that cassava-based bio-ethanol results in energy loss. In addition, the environmental impacts during the ethanol conversion stage of the lifecycle were quite large compared to other stages.

Theoretical Framework

In this section a dynamic general equilibrium optimal control model of cassava is constructed following the optimal control theory. The objective of the model is to determine the values of all relevant variables of the model in continuous time. The social planner problem is to maximize the sum of the discounted utility function of society under various constraints over an infinite time horizon. The arguments of the utility function are domestic consumption of food and of the composite commodity. In this study, 'food' is defined as food produced from cassava. The continuous time utility function is given by equation (1.1).

The objective function is:

$$\text{Maximize} \qquad W = \int_0^\infty e^{-rt} u(y_t^d, f_t^d) dt \qquad (1.1)$$

For the continuous time model, we consider an infinite time horizon from time period 0 to ∞ and the sum of utility takes the form of an integral. The objective function is to maximize utility of an economy (W) which is the summation of the discounted value of utility from time periods 0 to ∞, where $u(y_t^d, f_t^d)$ is the society utility function at time t of domestic composite commodity consumption (y_t^d) and domestic food consumption (f_t^d). We assume $u(y_t^d, f_t^d)$ is increasing and concave in consumption of y_t^d and f_t^d. The term e^{-rt} is a discount factor where r is the real interest rate and r is assumed to be constant along the time horizon. The utilized energy and energy produced from cassava are assumed to be perfect substitutes and are called ‘energy’. The composite commodity is composed of all other commodities not specifically modeled and is the numeraire commodity.

The constraints for the problem are (1.2-1.11):

$$\frac{dk_t}{dt} = I_t - \delta k_t \tag{1.2}$$

$$y_t^d + y_t^{ex} + I_t - F_y(k_t^y, N_t^y, L_t^y, U_t^y) = 0 \tag{1.3}$$

$$f_t^d + f_t^{ex} - F_f(k_t^f, N_t^f, C_t^f, U_t^f) \leq 0 \tag{1.4}$$

$$C_t^f + C_t^e - F_c(k_t^c, N_t^c, L_t^c, U_t^c) \leq 0 \tag{1.5}$$

$$E_t^c - F_e(k_t^e, N_t^e, C_t^e, U_t^e) \leq 0 \tag{1.6}$$

$$k_t - k_t^y - k_t^f - k_t^c - k_t^e = 0 \tag{1.7}$$

$$\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e = 0 \tag{1.8}$$

$$\overline{L} - L_t^y - L_t^c = 0 \tag{1.9}$$

$$U_t + E_t^c - U_t^y - U_t^f - U_t^c - U_t^e = 0 \tag{1.10}$$

$$p^f f_t^{ex} + p^y y_t^{ex} - p^u U_t = 0 \tag{1.11}$$

$$k_0 = k^0 \tag{1.12}$$

where the following descriptions describe the constraints:

Equation (1.2), $\frac{dk_t}{dt} = I_t - \delta k_t$ the net increase in the stock of physical capital at a point in time equals the gross investment (I_t) less its depreciation (δk_t), where δ is the depreciation rate and k_t is the stock of physical capital.

Equation (1.3), the production function for the composite commodity ($F_y(k_t^y, N_t^y, L_t^y, U_t^y)$), where $k_t^y, N_t^y, L_t^y,$ and U_t^y are capital, labor, land, and energy, respectively. The production function is expected to equal the sum of its domestic consumption (y_t^d), its export (y_t^{ex}) and gross investment (I_t).

Equation (1.4), the production function for food from cassava ($F_f(k_t^f, N_t^f, C_t^f, U_t^f)$) where C_t^f is the raw cassava which is used as feedstock for producing food. The food production is expected to be greater or equal to its domestic consumption (f_t^d) plus its export (f_t^{ex}).

Equation (1.5), the production function for raw cassava ($F_c(k_t^c, N_t^c, L_t^c, U_t^c)$) is greater or equal to the sum of raw cassava used in food production (C_t^f) and raw cassava used in energy production (C_t^e).

Equation (1.6), the production function for energy produced from cassava ($F_e(k_t^e, N_t^e, C_t^e, U_t^e)$) is greater or equal to energy produced from cassava (E_t^c).

Equation (1.7), $k_t - k_t^y - k_t^f - k_t^c - k_t^e = 0$ is a full employment constraint of capital used, that is, total capital stock equals the sum of stock of capital used in the composite commodity production (k_t^y), in food production (k_t^f), in raw cassava production (k_t^c) and in energy production (k_t^e).

Equation (1.8), $\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e = 0$ can be interpreted as the total labor used in all industries. The sum of labor used in the composite commodity production

(N_t^y), labor used in food production (N_t^f), labor used in raw cassava production (N_t^c), and labor used in energy from cassava production (N_t^e) equals total labor available in economy ($\overline{N}$).

Equation (1.9), $\overline{L} - L_t^y - L_t^c = 0$ is the total land available ($\overline{L}$) which is the sum of land used in the composite commodity production (L_t^y) and land used in raw cassava production (L_t^c).

Equation (1.10), $U_t + E_t^c - U_t^y - U_t^f - U_t^c - U_t^e = 0$ is a total energy constraint that is the total energy import (U_t) plus the energy produced from cassava (E_t^c) and equal to the sum of energy used in the composite commodity production (U_t^y), energy used in food production (U_t^f), energy used in raw cassava production (U_t^c) and energy used in energy produced from cassava production (U_t^e).

Equation (1.11), $p^f f_t^{ex} + p^y y_t^{ex} - p^u U_t = 0$ is the trade balance equation where:

$p^f f_t^{ex}$ is the value of food export where p^f is the relative price between food price and the composite commodity price, and f_t^{ex} is the food export quantity. $p^y y_t^{ex}$ is the net value of the composite commodity export. We consider the term of $p^y y_t^{ex}$ as the net value of the composite commodity export for covering the rest of the economy total exports minus the value of its total imports. p^y is a numeraire price and equals to one, and y_t^{ex} is the net export quantity of the composite commodity (the composite commodity export minus its import). $p^u U_t$ is the value of energy import. p^u is the relative price between energy price and the composite commodity price, and U_t is the energy import quantity.

Equation (1.12), $k_0 = k^0$ is the given value of initial stock of capital.

All production functions are assumed to be increasing and concave. In addition, total land and total labor available are fixed. The objective of the model is to maximize W over time period 0 to ∞ subject to the constraints (1.2) to (1.12).

The Present value Hamiltonian for the problem defined in (1.1-1.12) is;

$$H = e^{-rt}u(y_t^d, f_t^d) + \varphi_t(F^y(k_t^y, N_t^y, L_t^y, U_t^y) - y^d{}_t - y_t^{ex} - \delta k_t) \tag{1.13}$$

Where φ_t is the costate variable of the state variable.

The Present value Largrangian is

$$\begin{aligned}
L &= e^{-rt}u(y_t^d, f_t^d) + \varphi_t(F^y(k_t^y, N_t^y, L_t^y, U_t^y) - y_t^d - y_t^{ex} - \delta k_t) \\
&- \mu_f[f_t^d + f_t^{ex} - F^f(k_t^f, N_t^f, C_t^f, U_t^f)] \\
&- \mu_c[C_t^f + C_t^e - F^c(k_t^c, N_t^c, L_t^c, U_t^c)] \\
&- \mu_e[E_t^c - F^e(k_t^e, N_t^e, C_t^e, U_t^e)] \\
&+ \eta_k[k_t - k_t^y - k_t^f - k_t^c - k_t^e] \\
&+ \eta_N[\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e] \\
&+ \eta_L[\overline{L} - L_t^y - L_t^c] \\
&+ \eta_U[U_t + E_t^c - U_t^y - U_t^f - U_t^c - U_t^e] \\
&+ \eta_T(p^f f_t^{ex} + p^y y_t^{ex} - p^u U_t)
\end{aligned} \tag{1.14}$$

where; $\mu_f, \mu_c, \mu_e, \eta_k, \eta_N, \eta_L, \eta_U$, and η_T are the Largrangian multipliers for food production, raw cassava production, energy production, capital supply, labor supply, land supply, energy supply, and trade balance, respectively.

The present value necessary condition were derived using the maximum principle and are shown in Appendix A.

To develop the current value necessary condition, the costate variable and Largrangian multipliers are defined as follow:

For costate variable; $\lambda_t = e^{rt}\varphi_t$ and $\dot{\lambda}_t = re^{rt}\varphi_t + e^{rt}\dot{\varphi}_t$ where λ_t is the current value of costate variable. The current value Largrangian multipliers are defined as;

$\phi_k = e^{rt}\eta_k$, $\phi_N = e^{rt}\eta_N$, $\phi_L = e^{rt}\eta_L$, $\phi_U = e^{rt}\eta_U$, $\phi_T = e^{rt}\eta_T$,$\nu_C = e^{rt}\mu_C$, $\nu_f = e^{rt}\mu_f$, and $\nu_e = e^{rt}\mu_e$.

The current value necessary conditions for an internal solution are

$$\frac{\partial u_t^*(y_t^d, f_t^d)}{\partial y_t^d} - \lambda_t^* = 0 \tag{1.15}$$

$$\frac{\partial u_t^*(y_t^d, f_t^d)}{\partial f_t^d} - \nu_f^* = 0 \tag{1.16}$$

$$\dot{\lambda}_t = (r+\delta)\lambda_t^* - \phi_k^* \tag{1.17}$$

$$\dot{k}_t = F^{y*}(.) - y_t^{d*} - y_t^{ex*} - \delta k_t^* \tag{1.18}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial C_t^f} - \nu_C^* = 0 \tag{1.19}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial C_t^e} - \nu_C^* = 0 \tag{1.20}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial k_t^y} - \phi_k^* = 0 \tag{1.21}$$

$$\nu_f{}^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial k_t^f} - \phi_k{}^* = 0 \tag{1.22}$$

$$\nu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial k_t^c} - \phi_k{}^* = 0 \tag{1.23}$$

$$\nu_e{}^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial k_t^e} - \phi_k{}^* = 0 \tag{1.24}$$

$$\lambda_t{}^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial N_t^y} - \phi_N{}^* = 0 \tag{1.25}$$

$$\nu_f{}^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial N_t^f} - \phi_N{}^* = 0 \tag{1.26}$$

$$\nu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial N_t^c} - \phi_N{}^* = 0 \tag{1.27}$$

$$\nu_e{}^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial N_t^e} - \phi_N{}^* = 0 \tag{1.28}$$

$$\lambda_t{}^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial L_t^y} - \phi_L{}^* = 0 \tag{1.29}$$

$$\nu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial L_t^c} - \phi_L{}^* = 0 \tag{1.30}$$

$$\lambda_t{}^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial U_t^y} - \phi_U{}^* = 0 \tag{1.31}$$

$$\nu_f{}^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial U_t^f} - \phi_U{}^* = 0 \tag{1.32}$$

$$\nu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial U_t^c} - \phi_U{}^* = 0 \tag{1.33}$$

$$\nu_e^{\ *} \frac{\partial F^{*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial U_t^e} - \phi_U^{\ *} = 0 \tag{1.34}$$

$$\begin{aligned} &\nu_f^{\ *}(f_t^{d*} + f_t^{ex*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)) = 0 \\ &f_t^{d*} + f_t^{ex*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f) \le 0, \nu_f^{\ *} \ge 0 \end{aligned} \tag{1.35}$$

$$\begin{aligned} &\nu_c^{\ *}(C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)) = 0 \\ &C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c) \le 0, \nu_c^{\ *} \ge 0 \end{aligned} \tag{1.36}$$

$$\begin{aligned} &\nu_e^{\ *}(E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)) = 0 \\ &E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e) \le 0, \nu_e^{\ *} \ge 0 \end{aligned} \tag{1.37}$$

$$\overline{L} - L_t^{y*} - L_t^{c*} = 0 \tag{1.38}$$

$$k_t^* - k_t^{y*} - k_t^{f*} - k_t^{c*} - k_t^{e*} = 0 \tag{1.39}$$

$$\overline{N} - N_t^{y*} - N_t^{f*} - N_t^{c*} - N_t^{e*} = 0 \tag{1.40}$$

$$U_t^{\ *} + E_t^{c*} - U_t^{y*} - U_t^{f*} - U_t^{c*} - U_t^{e*} = 0 \tag{1.41}$$

$$-\nu_e^{\ *} + \phi_U^{\ *} = 0 \tag{1.42}$$

$$\lambda_t^* = p^y \phi_t^* \tag{1.43}$$

$$\nu_f^{\ *} = p^f \phi_t^* \tag{1.44}$$

$$\phi_U^{\ *} = p^u \phi_t^* \tag{1.45}$$

$$p^f f_t^{ex*} + p^y y_t^{ex*} = p^u U_t^{\ *} \tag{1.46}$$

where the following descriptions describe the necessary condition equations.

Equation (1.15) states that the marginal utility of the composite commodity consumption equals the value of capital stock in each time period. Equation (1.16) is the marginal utility of food consumption equals to the shadow value of food in each time period. Equation (1.17) is the law of motion of the costate variable, λ_t^*, that is, the rate of change in value of capital stock equals the net value of the marginal product of capital. The costate variable can be interpreted as the shadow value of stock of capital in each time period. In equation (1.18) the rate of change in the state variable (stock of capital) is the gross investment minus its depreciation. Equations (1.19) and (1.20) both have an expression equal to shadow value of raw cassava. Raw cassava has the same marginal value in food production and energy production in each time period. Equations (1.21)-(1.24) state that optimal values of the marginal product of capital in all production functions in each time period have to equal the shadow value of capital. Equations (1.25)-(1.28) state that the optimal value of the marginal product of labor in all production functions is equal to the shadow value of labor in each time period. Equations (1.29)-(1.30) show that the optimal value of the marginal product of land in the composite commodity production and raw cassava production is equal to the shadow value of land in each time period. Equations (1.31)-(1.34) can be interpreted as the value of the marginal product of utilized energy in all production functions in each time period which is equal to the shadow value of utilized energy. Equations (1.35)-(1.37) are the optimal current value of food production, raw cassava production, and energy production in each time period according to the Kuhn-Tucker conditions. Equations (1.38)-(1.41) are full employment constraints of land, capital, labor and energy in each time period respectively. Equation (1.42) shows that the shadow value of domestic energy production is equal to the shadow value of imported energy in each time period. Equation (1.43) shows that the optimal value of exported composite commodity is equal to the shadow value of the composite commodity in each time period. Equation (1.44) shows that the optimal value of exported food equals to the shadow value of food. Equation (1.45) shows that the optimal value of imported energy equals to the shadow value of energy. And equation (1.46) is the trade balance constraint for the international sector.

The Maximum Principle

The maximum principle in the optimal control theory is stated as set of conditions that exist along the optimal path. Equations (1.15)-(1.46) state these conditions and were derived from the Largrangian function (1.14). The set of solutions that satisfy the current value necessary equations (1.15)-(1.46) is composed of one state variable (k_t^*), one costate variable (λ_t^*), eight Largrangian multipliers (ϕ_k^*, ϕ_N^*, ϕ_L^*, ϕ_U^*, ϕ_T^*, ν_C^*, ν_f^* and ν_e^*), and control variables (the other twenty-two variables). In this section, we will discuss some selected variables in the set of solutions that satisfies the maximum principle.

State Variable (k_t)

Equation (1.18) $\dot{k}_t = F^{y*}(.) - y_t^{d*} - y_t^{ex*} - \delta k_t^*$ describes the rate of change in capital stock between time periods. At the initial time, there are k_0 units of capital available in the economy. The rate of change in capital stock ($\dot{k}_t$) depends on the gross production of the composite commodity ($F^{y*}(.)$) over the sum of consumption of the composite commodity and the net export of the composite commodity ($y_t^{d*} + y_t^{ex*}$) and its depreciation (δk_t^*).

At the stationary state, the model corresponds to $\dot{\lambda}_t^* = 0$ and $\dot{k}_t^* = 0$. Thus in the stationary state, equation (1.17) and (1.18) are equal to zero. We can interpret equation (1.18) as the following:

$$F^{y*}(.) - y_t^{d*} - y_t^{ex*} = \delta k_t^* \qquad (1.47)$$

Since there is no change in stock of capital in the stationary state, the gross investment ($I_t = F^{y*}(.) - y_t^{d*} - y_t^{ex*}$) equals the depreciation of capital.

Costate Variable *(λ_t)*

Equation (1.17), $\dot{\lambda}_t = (r+\delta)\lambda_t^* - \phi_k^*$ is the law of motion of the costate variable (λ_t). After we substitute equation (1.21) into (1.17), it yields:

$$\dot{\lambda}_t^* = [(MP_{ky}{}^* - \delta) - r]\lambda_t^* \qquad (1.48)$$

The equation (1.48) can be state as the rate of change in the value of capital stock between time periods. It gives the time path of the shadow value of the capital stock. $MP_{ky}{}^*$ is the marginal product of capital in the production of the composite commodity , the numeraire commodity, δ is the depreciation rate of a unit of capital through time, and r is the discount rate of time preference. The costate variable, λ_t, is the shadow value of capital stock and is interpreted as the present value of the net return stream of a unit of capital.

The above equation (1.48) can be written as

$$MP_{ky}{}^* \cdot \lambda_t^* = (\delta + r) \cdot \lambda_t^* - \dot{\lambda}_t^* \qquad (1.49)$$

The term $MP_{ky}{}^{*} \cdot \lambda_t^{*}$ is the gross return to a unit of capital or the value of the marginal product of capital. We can derive the time path of the gross return to a unit of capital by using depreciation at the rate δ. Therefore the discounted present value of the gross return stream is

$$PV(0) = \int_0^{\infty} e^{-rt}(MP_{ky}{}^{*} \cdot \lambda_t^{*}) \cdot e^{-\delta t} dt$$

Substitute equation (1.49), we get

$$PV(0) = \int_0^{\infty} e^{-rt}((r+\delta) \cdot \lambda_t^{*} - \frac{d\lambda^{*}}{dt}) \cdot e^{-\delta t} dt$$

Using integration by parts,

$$PV(0) = -e^{-(r+\delta)\infty} \cdot \lambda(\infty)^{*} + e^{-(r+\delta)0} \cdot \lambda(0)^{*}$$

If the discount and depreciation rate at the infinity time is going to zero ($\lim_{t\to\infty} e^{-(r+\delta)t} = 0$), we can conclude that $PV(0) = \lambda(0)^{*}$ is the present value of net return on a unit of capital through time.

In the stationary state, the rate of change in value of capital stock is constant at zero ($\dot{\lambda}_t = 0$) and the shadow value of capital stock is assumed to equal to one ($\lambda_t = 1$). Equation (1.49) can be expressed as equation (1.50).

$$(r+\delta) = MP_{ky}{}^{*} \qquad (1.50)$$

The marginal product of capital for the composite commodity production ($MP_{ky}{}^{*}$) equals the rental price of a unit of capital $(r+\delta)$ or the implicit user cost of capital for the composite commodity.

Consumption, Production, and Allocation of Resources in Economy

In the stationary state, the consumption, production, and allocation of resources in the economy are allocated at the optimal level. Some variables from the optimal set of solutions are selected to describe the stationary state production, consumption, and allocation of resources in an economy:

Food. The optimal food consumption can be expressed in the relationship between food and the composite commodity as

$$\frac{MU_{f^d}{}^*}{MU_{y^d}{}^*} = \frac{\nu_f{}^*}{\lambda_t^*} \tag{1.51}$$

It is derived from equations (1.15) and (1.16). The ratio of the marginal utility between food and the composite commodity is equal to the relative prices between food and the composite commodity. It can be explained that the optimal consumption of food is decided by relative prices between food and the composite commodity.

The optimal allocation of factors for producing food is displayed in equation (1.52). It is derived from equations (1.19), (1.22), (1.26), and (1.32).

$$\frac{MP_{kf}{}^*}{MP_{ky}{}^*} = \frac{MP_{Nf}{}^*}{MP_{Ny}{}^*} = \frac{MP_{Lc}{}^*}{MP_{Ly}{}^*} \cdot MP_{Cf}{}^* = \frac{MP_{Uf}{}^*}{MP_{Uy}{}^*} = \frac{\lambda_t^*}{\nu_f{}^*} \tag{1.52}$$

Where; $\frac{MP_{Lc}{}^*}{MP_{Ly}{}^*} \cdot MP_{Cf}{}^* = \frac{\lambda_t^*}{\nu_f{}^*}$ is computed from equation (1.19), (1.29), and (1.30). We

divine equation (1.19) by (1.29) to get $\frac{MP_{Cf}{}^*}{MP_{Ly}{}^*} \cdot \frac{\phi_L}{\nu_c} = \frac{\lambda_t^*}{\nu_f{}^*}$ and substitute $\frac{\phi_L}{\nu_c} = MP_{Lc}$ from

equation (1.30) to get the result.

Equation (1.52) is the optimal allocation of capital, labor, raw cassava, and energy for producing food. The relationship is shown in the ratio of the marginal product for each input to produce food and the composite commodity. It states that the optimal combination of production of two goods (food and the composite commodity) from each input (capital, labor, raw cassava, and energy) is equal to the relative shadow prices between two goods. We can call the above relationship the marginal rate of transformation ($ROT_i^{f\&y}$) of each input (i : capital, labor, and energy) for producing two goods (f & y : food and the composite commodity). Because raw cassava is not used as input in the composite commodity production, we express the optimal use of raw cassava as the marginal product of raw cassava for producing food ($MP_{Cf}{}^*$) multiplied by the marginal rate of transformation of land to produce raw cassava and the composite commodity ($\frac{MP_{Lc}{}^*}{MP_{Ly}{}^*} = ROT_L^{c\&y}$). We can conclude equations (1.51) and (1.52) as the optimal consumption, production and allocation for food relative to the composite commodity. The optimal consumption, production, and allocation for food are described in the relative shadow value of food and the composite commodity.

Raw cassava. The optimal allocation of capital, labor, land, and energy for producing raw cassava is derived from equations (1.23), (1.27), (1.30), and (1.33):

$$\frac{MP_{kc}{}^*}{MP_{ky}{}^*} = \frac{MP_{Nc}{}^*}{MP_{Ny}{}^*} = \frac{MP_{Lc}{}^*}{MP_{Ly}{}^*} = \frac{MP_{Uc}{}^*}{MP_{Uy}{}^*} = \frac{\lambda_t{}^*}{\nu_c{}^*} \qquad (1.53)$$

We can call the above relationship in equation (1.53) the marginal rate of product transformation ($ROT_i^{c\&y}$) of each input (i : capital, labor, land, and energy) for producing two goods (c & y : raw cassava and the composite commodity). The optimal production and allocation for raw cassava is equal to the relative shadow value of raw cassava and the composite commodity.

Energy. The optimal allocation of capital, labor, land, and energy for producing energy is derived from equations (1.20), (1.24), (1.28), and (1.34):

$$\frac{MP_{ke}{}^{*}}{MP_{ky}{}^{*}} = \frac{MP_{Ne}{}^{*}}{MP_{Ny}{}^{*}} = \frac{MP_{Lc}{}^{*}}{MP_{Ly}{}^{*}} \cdot MP_{Ce}{}^{*} = \frac{MP_{Ue}{}^{*}}{MP_{Uy}{}^{*}} = \frac{\lambda_t^{*}}{\nu_e^{*}} \tag{1.54}$$

Where; $\frac{MP_{Lc}{}^{*}}{MP_{Ly}{}^{*}} \cdot MP_{Ce}{}^{*} = \frac{\lambda_t^{*}}{\nu_e^{*}}$ is computed from equation (1.20), (1.29), and (1.30).

Equation (1.20) is divined by (1.29) to get $\frac{MP_{Ce}{}^{*}}{MP_{Ly}{}^{*}} \cdot \frac{\phi_L}{\nu_c} = \frac{\lambda_t^{*}}{\nu_e^{*}}$ and substituted by $\frac{\phi_L}{\nu_c} = MP_{Lc}$ from equation (1.30) to get the result.

We can call the above relationship in equation (1.54) the marginal rate of product transformation ($ROT_i^{e\&y}$) of each input (i : capital, labor, and energy) for producing two goods (e & y : energy and the composite commodity). Using the same reason used for food, we state the optimal use of raw cassava as the marginal product of raw cassava for producing energy ($MP_{Ce}{}^{*}$) multiplied by the marginal rate of transformation of land to produce raw cassava and the composite commodity ($\frac{MP_{Lc}{}^{*}}{MP_{Ly}{}^{*}} = ROT_L^{c\&y}$). The optimal production and allocation for energy is equal to the relative shadow value of energy and the composite commodity.

Empirical Model

The dynamic general equilibrium optimal control model of cassava is developed to determine the set of all relevant variables in the economy. The economy is assumed to have four production sectors, which are the composite commodity, food, raw cassava, and energy. The optimal control theory is used as the tool of analysis. The model maximizes the sum of discounted utility of society over an infinite time horizon.

The assumptions of the model in this study are (1) perfect substitution between utilized energy and ethanol from cassava, and (2) fixed interest rate and fixed depreciation rate over the time horizon. In calibration, the model assumes Cobb-Douglas functions for the utility function and the production functions for the economy.

The Model with Cobb Douglas Functions

This section develops and specifies functions for the model to derive numerical results for an economy. The model assumes Cobb-Douglas function as the utility function and the production functions, which has the advantage of finding a unique solution from increasing and concave function qualification. In this study, the model has one utility function (1.1) and four production functions in equations (1.3)-(1.6) of the composite commodity, food, raw cassava and energy, respectively. The model can be specified in Cobb-Douglas functions as

$$W = \int_0^T e^{-rt}[(y_t^d)^{\alpha} \cdot (f_t^d)^{\beta}]dt \qquad (1.55)$$

$$y_t^d + y_t^{ex} + I_t - \left[(k_t^y)^{\gamma 1} \cdot (N_t^y)^{\rho 1} \cdot (L_t^y)^{\sigma 1} \cdot (U_t^y)^{\delta 1}\right] = 0 \qquad (1.56)$$

$$f_t^d + f_t^{ex} - \left[(k_t^f)^{\gamma 2} \cdot (N_t^f)^{\rho 2} \cdot (C_t^f)^{\tau 2} \cdot (U_t^f)^{\delta 2}\right] \leq 0 \qquad (1.57)$$

$$C_t^f + C_t^e - \left[(k_t^c)^{\gamma 3} \cdot (N_t^c)^{\rho 3} \cdot (L_t^c)^{\sigma 3} \cdot (U_t^c)^{\delta 3} \right] \leq 0 \qquad (1.58)$$

$$E_t^c - \left[(k_t^e)^{\gamma 4} \cdot (N_t^e)^{\rho 4} \cdot (C_t^e)^{\tau 4} \cdot (U_t^e)^{\delta 4} \right] \leq 0 \qquad (1.59)$$

where α and β are the preference parameters of the utility function for the composite commodity and for food respectively. $\gamma 1$-$\gamma 4$ are output elasticity of capital for the composite commodity, for food, for cassava, and for utilized energy, respectively. $\rho 1$-$\rho 4$ are output elasticity of labor for the composite commodity, for food, for cassava, and for utilized energy, respectively. $\sigma 1$ and $\sigma 3$ are output elasticity of land for the composite commodity and for cassava. $\tau 2$ and $\tau 4$ are output elasticity of cassava for food and for utilized energy. And $\delta 1$-$\delta 4$ are output elasticity of utilized energy for the composite commodity, for food, for cassava, and for utilized energy, respectively.

Data and Parameters

The model is calibrated using Thailand data. The objective of the simulation is to analyze the consumption, production, and allocation for the Thai economy. The data that is used to estimate parameters in the model is the national yearly data in 2007 for some parameters and the existing research data for other parameters.

First, in the utility function α and β are the preference parameters of the utility function for the composite commodity and for food, respectively. The assigned value for α and β in this study is estimated by using expenditure share in the total expenditure. The share of the composite commodity in national consumption is set to α =0.9889 and it implies that the share of food from cassava in national consumption is set to

β = 0.01106. This data is obtained from of Office of National Economic and Social Development Board (2009).

Second, the output elasticity can be obtained by using factor share of the output as follows:

The composite commodity production. The factors used in the composite commodity production are capital, labor, land, and energy. The data for factor shares is obtained from Office of National Economics and Social Development Board (2009). The capital share in the composite commodity production is set to γ_1=0.65316, labor in the composite commodity production is set to ρ_1=0.2832, land share in the composite commodity production is set to σ_1=0.038 and energy share in the composite commodity production is set to δ_1=0.02564.

Food production. The production function of food has four factors: capital, labor, raw cassava, and energy. The data for factor shares is obtained from the research study of Export-Import Bank of Thailand (2008). The capital share in food production is set to γ_2 =0.1372, labor share in food production is set to ρ_2=0.0696, raw cassava share in food production is set to τ_2=0.600 and energy share in food production is set to δ_2=0.1932.

Raw cassava production. The raw cassava production function has the same factors as the composite commodity production function (capital, labor, land and energy). The data for factor shares is obtained from Office of Agriculture Economics (2009). The capital share in raw cassava production is set to γ_3=0.3041, labor share in raw cassava production is set to ρ_3=0.5444, land share in raw cassava production is set to σ_3=0.1108 and energy share in raw cassava production is set to δ_3=0.0403.

Energy production. The energy production function has four factors: capital, labor, raw cassava, and energy. The data of factor shares is obtained from the research study of Yoosin and Sorapipatana (2007). The capital share in energy production is set to γ_4=0.449, labor share in energy production is set to ρ_4=0.0079, raw cassava share in energy production is set to τ_4=0.5415 and energy share in energy production is set to δ_4=0.00151.

Third, the parameter $\bar{L}$ is the total land area available for production. The data for land parameters is obtained from Office of Agricultural Economics (2009) by using total agriculture land available for all agriculture production. $\bar{L}$ is set to 20.82 million hectares. $\overline{N}$ is the total labor available in economy. The data for the labor parameter is obtained from National Economic and Social Development Board. $\overline{N}$ is set to be 37.7 million persons.

Fourth, the relative export and import prices are assigned in the relative price by using the composite commodity as the numeraire. The export price of the composite commodity is set to be 1, the relative export price of food is set to be $\frac{v_f}{\lambda_t}$, and the relative import price of energy is set to be $\frac{\phi_U}{\lambda_t}$.

Last, the interest rate and depreciation rate are assigned to be 3.5% and 5%, respectively. The interest rate is assigned following the description in the World Fact

Book (Central Intelligence Agency, 2010). The Central Bank discount rate is defined as the interest rate that the Central Bank charges commercial banks for loans to meet temporary shortage of funds. In this study, the discount rate or interest rate is set to 3.5% for average years of 2007-2008. The depreciation rate is assigned following the study of Tanboon (2008). The annual depreciation rate is set from the annual depreciation divided by gross capital stock at 1988 prices for use in the structural model for The Bank of Thailand policy analysis. Thus in this study, the depreciation rate is calculated by using Tanboon's concepts and using data in from 2007. The average annual depreciation rate of real sector (agriculture sector and industrial sector) in 2007 is set to 5%.

Results

This section describes the stationary state solution, the stationary state evaluation, and the optimal time path for the set of variables by solving the system of equations (1.15)-(1.46) and substituting the above defined parameter values. The results are explained as follows:

Calibration Results

The stationary state solution of the model is obtained by solving the system of current value necessary equations (1.15)-(1.46) with $\frac{dk}{dt} = \frac{d\lambda}{dt} = 0$ and using functions of (1.55)-(1.59). The set of solutions for all variables in the stationary state is shown in Appendix B, Table B.1. Due to the large difference between the solution values of variables from calibration and the defined parameter values from the Thai data, the model is applied with a new value of τ_2 to reduce the difference between them. The explanation of the calibration evaluation is described in the next section. The old parameter value of τ_2 is set to be 0.600 and the new value for τ_2 is changed to be 0.47.

The system of equations generates values of variables at the maximum point which are shown in Table 1. The model generates the quantities of consumptions, the quantities of productions, the quantities of factors allocation, the quantities of export and import, and the shadow prices. The equilibrium value of the composite commodity is 1540.483 units, which includes 910.483 units of domestic composite commodity consumption, 34.948 units of the composite commodity for export, and 595.052 units of gross investment. The optimal production of food is 1.840 units, which are 1.005 units for domestic consumption and 0.835 units for export. The optimal value of raw cassava production for food is 1.482 units and for energy is 0.054 units. The energy production from cassava is 0.3048 units, while imported energy is 21.389 units.

The production factors (capital, labor, land, energy) are allocated in stationary state and are shown in Table 1. The equilibrium allocation of capital for the composite commodity, for food, for cassava, and for energy is 11834, 30.090, 33.116, and 3.275 units, respectively. The labor used in each production is 37.170, 0.110, 0.418, and 0.001 units, for the composite commodity, for food, for cassava, and for energy, respectively.

The allocation of energy used for the composite commodity, for food, for cassava, and for energy is 19.736, 1.774, 0.179, and 0.004 units, respectively. The land allocated is 20.5 units for the composite commodity production and 0.349 units for cassava production.

Table 1.1

Stationary State Solution for Endogenous Variables

Variables	Value	Description
y_t^d	910.4835	The composite commodity
f_t^d	1.0051	Food from cassava
y_t^{ex}	34.9488	Net composite commodity for export
f_t^{ex}	0.8350	Food from cassava for export
U_t	21.3899	Imported energy
$\left[(k_t^y)^{\gamma 1}\cdot(N_t^y)^{\rho 1}\cdot(L_t^y)^{\sigma 1}\cdot(U_t^y)^{\delta 1}\right]$	1,540.4830	The composite commodity production
k_t^y	11,834.5340	Capital for the composite commodity
N_t^y	37.1702	Labor for the composite commodity
L_t^y	20.5000	Land for the composite commodity
U_t^y	19.7365	Energy for the composite commodity
$\left[(k_t^f)^{\gamma 2}\cdot(N_t^f)^{\rho 2}\cdot(C_t^f)^{\tau 2}\cdot(U_t^f)^{\delta 2}\right]$	1.8401	Food from cassava production
k_t^f	30.0900	Capital for food
N_t^f	0.1106	Labor for food
C_t^f	1.4828	Raw cassava for food
U_t^f	1.7747	Energy for food
$\left[(k_t^c)^{\gamma 3}\cdot(N_t^c)^{\rho 3}\cdot(L_t^c)^{\sigma 3}\cdot(U_t^c)^{\delta 3}\right]$	1.5367	Cassava production
k_t^c	33.1160	Capital for cassava
N_t^c	0.4181	Labor for cassava
L_t^c	0.3498	Land for cassava
U_t^c	0.1789	Energy for cassava
$\left[(k_t^e)^{\gamma 4}\cdot(N_t^e)^{\rho 4}\cdot(C_t^e)^{\tau 4}\cdot(U_t^e)^{\delta 4}\right]$	0.3048	Energy production
k_t^e	3.2750	Capital for energy
N_t^e	0.0011	Labor for energy
C_t^e	0.0539	Raw cassava for energy
U_t^e	0.0046	Energy for energy
λ_t	1.0000	shadow price of the composite commodity
ϕ_k	0.0849	shadow price of capital
ϕ_N	11.7281	shadow price of labor
ϕ_L	2.8554	shadow price of land
ϕ_U	2.0290	shadow price of utilize energy
ϕ_t	1.0000	shadow price of trade
ν_f	10.1308	shadow price of food
ν_c	5.9085	shadow price of raw cassava
ν_e	2.0290	shadow price of energy from cassava

The equilibrium solution gives the value of relative shadow prices of the composite commodity, food, cassava, and energy as 1, 10.1308, 5.9085, and 2.0290 respectively. In addition, the shadow prices of factors are 0.0894 for capital, 11.7281 for labor, 2.8554 for land, and 2.0290 for energy.

Calibration Evaluation

In calibrating the model it was necessary to adjust some of the parameters from those stated above. First, the parameters from actual data are substituted and computed for generating the stationary state solution. Second, the difference between solutions and actual data was computed in absolute percentage differences. Third, the new set of parameters is used for generating stationary state solution and computing the difference between the solution and actual data again. After that, we compare the different between two values of the absolute percentage difference and select the lesser one. Last, we repeat the above steps until the set of parameters generates the minimum value of the average absolute percentage difference.

After comparing the results of the sets of parameters in calibration, the model that gives the closest solution to capture actual Thai data in the year 2007 is selected.

The set of parameters that generates the minimum value of percentage difference is the set that has τ_2 =0.470. The first data set that is defined by Thailand data gives 9.8423% of the average absolute percentage difference while the new data set with τ_2 =0.470 gives 9.4509%. The values of absolute percentage from the data set with τ_2 =0.470 express the lesser value in the average absolute percentage difference. The new data set affects the structure of food production function by changing it from a constant return to scale function to a decreasing return to scale function. The comparisons of the results are available in Appendix B, Table B.1 and Table B.2.

Simulation Results

The objective of this section is to find a policy function or a time independent numerical decision rule that solves the model outlined above. An infinite time horizon optimal control model for the Thai economy has two differential equations and thirty algebraic equations in the first order necessary conditions. Due to the complex structure of the model and many variables in the model, the solution time path cannot be directly solved for the state variable (k_t^*) and the costate variables (λ_t^*). In this section, the solution time paths are solved by two numerical methods: (1) Linear approximation of the differential equations as in Leonard and Van Long (1992), and (2) Runke-Kutta reverse shooting method as in Judd (1998).

Solution time path for linear approximation method. The general solution to linear equations is given by:

$$k(t) = C_1 v_{11} e^{\pi_1 \cdot t} + C_2 v_{12} e^{\pi_2 \cdot t} + k_{ss} \qquad (1.60)$$

$$\lambda(t) = C_1 v_{21} e^{\pi_1 \cdot t} + C_2 v_{22} e^{\pi_2 \cdot t} + \lambda_{ss} \qquad (1.61)$$

where C_i are the constant of integration and v_{ij} are the elements of Eigen vectors. The numerical results of the problem are C_1 =0, C_2 =1450.016, v_{12} = -0.9999, v_{22} = 1.389e-06, π_2 = -1.7505, k_{ss} = 11,901.016, and λ_{ss} = 0.9172. The details of the solution to the time path by linear approximation are discussed in Appendix C, and the relationship between $k(t)$ and $\lambda(t)$ in equation (1.60) and (1.61) shown by solid line in Figure 1.1.

Solution time path for Runke-Kutta reverse shooting method. Since the time path solution from the linear approximation method has a high speed of adjustment to stationary state, the method of Runke-Kutta reverse shooting is used to solve the numerical policy function solution to capture the adjustment of the solution time path at a very small step size to get more accuracy. The step of computing the solution time path for Runke-Kutta reverse shooting method is described in Appendix C.

An approximation of the capital stock policy function $K'(\lambda(t))$ in equation (1.62) is generated by using reverse shooting method.

$$K'(\lambda(t)) = \frac{\dot{k}}{\dot{\lambda}} = \frac{g(k_t, \lambda_t)}{f(k_t, \lambda_t)} \tag{1.62}$$

where the step of computing equation (1.62) is shown in Appendix C.

The solution for the policy function is generated from a point close to stationary state and move backwards to a beginning point. The result is shown by the dashed line in Figure 1.1.

In Figure 1.1., the dashed line represents policy function approximation from the reverse shooting method and the solid line shows the linear approximation relationship between $k(t)$ and $\lambda(t)$ in equations (1.60) and (1.61). The vertical axis is the value of the costate variable or the shadow value of the composite commodity. The horizontal axis is the value of the stock of capital. The policy function begins (in dashed line) at a stationary state point where stock of capital equals 11,901. 016 and value of the shadow price of the composite commodity (the relative shadow price is 1) equals 0.9172.

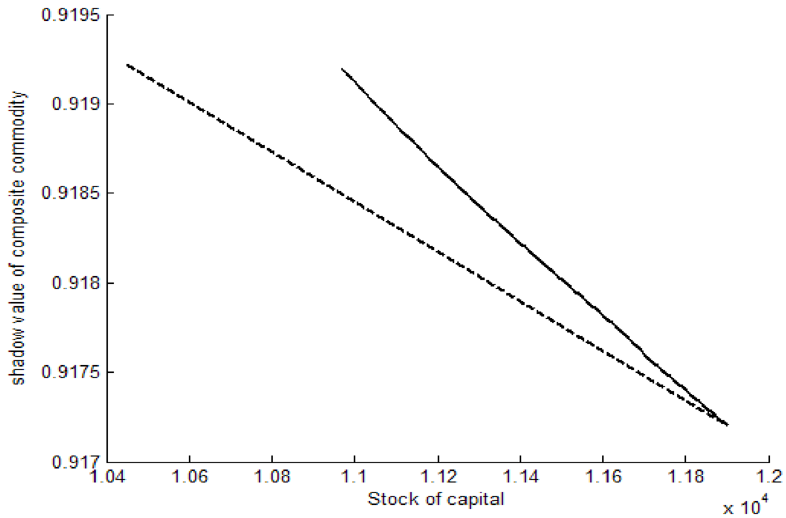

Figure 1.1. The reverse shooting of the policy function and the linear approximation relationship between $k(t)$ and $\lambda(t)$

We can interpret that, from the initial point, the shadow price of the composite commodity decreases and the stock of capital increases through time until they go to the stationary state.

In Figure 1.2, the first graph shows the approximation of the optimal path for stock of capital (left picture) and the shadow value of the capital (right picture) by linear approximation method and reverse shooting method. The linear approximation method is simulated 200 iterations with the beginning stock of capital k_0 = 10,401.016. After six iterations, the stock of capital goes to long run optimal level (the solid line). The reverse shooting method is set the beginning stock of capital to k_0 = 11,161.016 and it requires 73 iterations through time to reach the long run optimal path (dashed line).

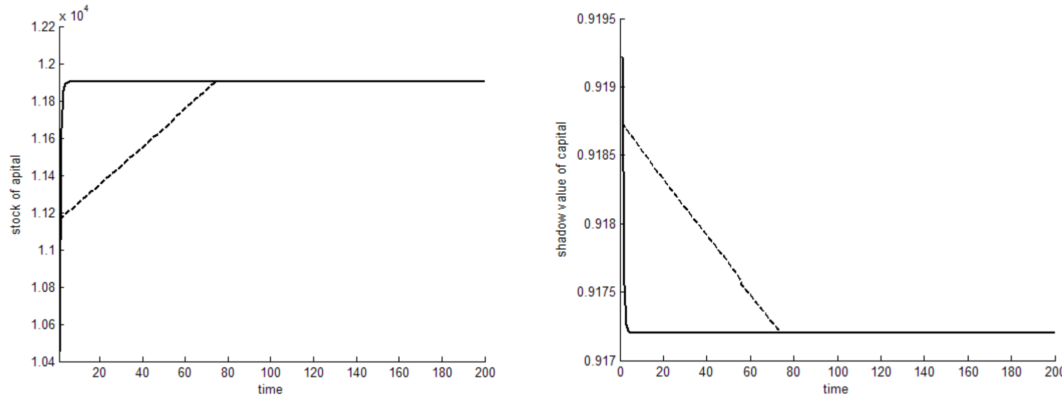

Figure 1.2. Approximation of the optimal time path of the stock of capital (left) and the shadow value of the capital stock (right)

The beginning stock of capital of the reverse shooting method is larger than that of the linear approximation method because after 73 iterations the solution ceases to be meaningful. Thus the simulation from the reverse shooting method needs to stop at about k_t = 11,161.016 and is set at the beginning point of k_0. In Figure 1.2, the second graph is the time path shadow value of the capital stock. Due to the difference in the beginning stock of capital, they have different beginning values of shadow value of capital. The shadow values decrease through time until they reach long run optimal path at 0.9172.

Figure 1.3 shows the approximated time path of gross investment and consumption. The time path of gross investment decrease through time until it reaches long run optimal level at 383.824. The dashed line in both graphs represents the solution time path for the reverse shooting method, while the solid line represents the solution for the linear approximation. An adjustment for consumption increases when time increases and reaches the optimal long run consumption at 1,118.290.

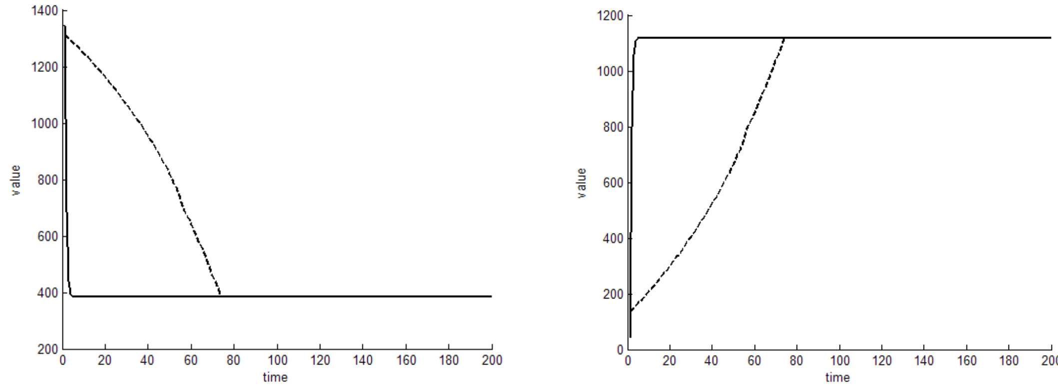

Figure 1.3. Approximation of the optimal time path of the gross investment (left) and consumption (right)

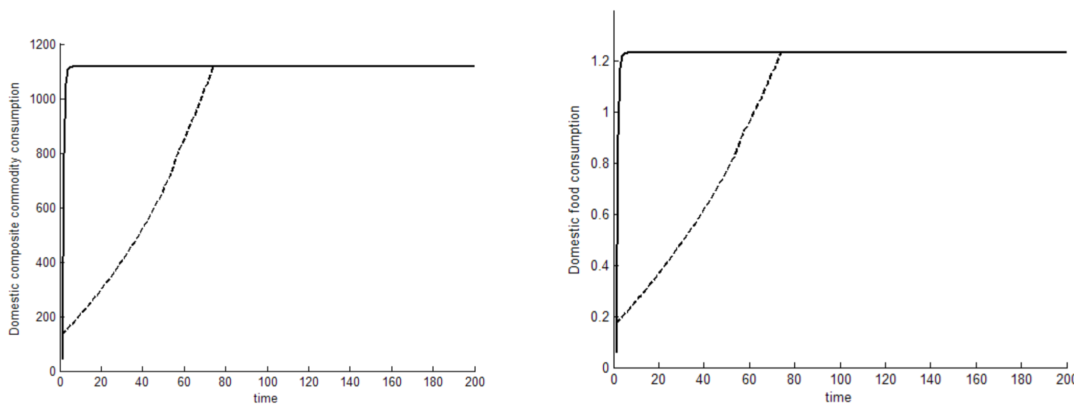

Figure 1.4. Approximation of the optimal time path of the domestic composite commodity consumption (left) and domestic food consumption (right)

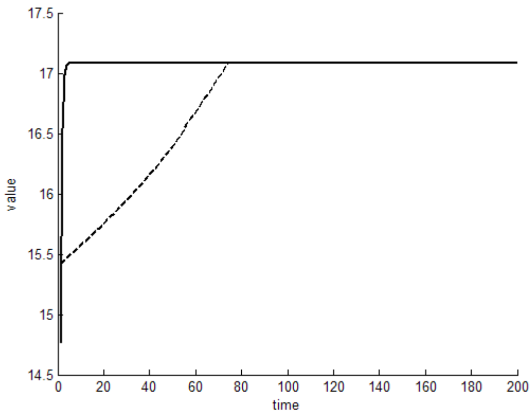

Figure 1.5. Approximation of the optimal time path of the domestic ethanol production

The optimal path for consumption is the domestic total consumption in the economy which is composed of domestic composite commodity and domestic food.

Figure 1.4 shows the optimal path of domestic composite commodity and domestic food consumption. Both graphs of optimal path of consumption increase through time until they reach long run optimal level where the composite commodity consumption equals 1,117.057 and food consumption equals 1.233.

Figure 1.5 shows the optimal path of domestic ethanol production. The time path of ethanol production starts from time zero and increases in production through time until reaching long run optimal level of production at 17.084.

Conclusion

The study analyzes a dynamic general equilibrium model of cassava based on the optimal control problem for an infinite time horizon. The model is developed and calibrated with Thailand data. The objective of the model is to maximize total utility of society, and it highlights food from cassava as a separate commodity. The constraints of the model are defined to capture all activities in the economy to represent food consumption and energy production from cassava. The parameters in the calibration are based on Thai data in the year 2007. To evaluate the model, the absolute percentage difference is used to compare between the actual data and the calibration results. The model that gives minimum value of absolute percentage difference is selected and used in simulation.

The model is simulated to find the optimal time path using two methods which are the linear approximation method and the reverse shooting method. Different methods generate different sets of approximation of the optimal time path. The linear approximation has a high speed to reach the long run equilibrium while the reverse shooting of the policy function has the advantage generating steps of adjustment to reach the long run equilibrium. Thus the approximation of the policy function for capital is generated by using Runke-Kutta reverse shooting method. The results of the model describe optimal consumption, production and allocation of resources in the economy in case of producing cassava for food or for energy. The calibration based on Thai data gives satisfactory results close to actual data when we multiply the results with a scale factor.

A dynamic general equilibrium model of cassava is developed to analyze the conflict between using cassava for food or for energy. The model allocates resources in the economy over a period of time using the necessary conditions from an application of the maximum principle. The results of the model can be used as information for decision makers or policy makers to plan their economy. Achieving sustainable development of an economy concerning on bio-fuel production requires appropriate energy crop production planning for long run resource allocation. This model is one tool to provide information for planning the consumption, production and allocation of resources in the economy to achieve a sustainable development goal.

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Appendix A

Present Value Necessary Conditions

From equation (1.14), the maximum principle yields the thirty equations of first order conditions and two equations of differential equations, which are called present value necessary conditions (A1.1-A1.32);

$$\frac{\partial L}{\partial y_t^d} = e^{-rt}\,\frac{\partial u_t^*(y_t^{d*}, f_t^{d*})}{\partial y_t^d} - \varphi_t^* = 0 \qquad \text{(A1.1)}$$

$$\frac{\partial L}{\partial f_t^d} = e^{-rt}\,\frac{\partial u_t^*(y_t^{d*}, f_t^{d*})}{\partial f_t^d} - \mu_f^* = 0 \qquad \text{(A1.2)}$$

$$-\frac{\partial L}{\partial k_t} = \dot{\phi}_t = \delta\phi_t^* - \eta_k^* \qquad \text{(A1.3)}$$

$$\frac{dk_t}{dt} = F^y(^*) - y_t^{d*} - y_t^{ex*} - \delta k_t^* \qquad \text{(A1.4)}$$

$$\frac{\partial L}{\partial C_t^f} = \mu_f^*\,\frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial C_t^f} - \mu_C^* = 0 \qquad \text{(A1.5)}$$

$$\frac{\partial L}{\partial C_t^e} = \mu_e^*\,\frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial C_t^e} - \mu_C^* = 0 \qquad \text{(A1.6)}$$

$$\frac{\partial L}{\partial k_t^y} = \phi^*\,\frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial k_t^y} - \eta_k^* = 0 \qquad \text{(A1.7)}$$

$$\frac{\partial L}{\partial k_t^f} = \mu_f^*\,\frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial k_t^f} - \eta_k^* = 0 \qquad \text{(A1.8)}$$

$$\frac{\partial L}{\partial k_t^c} = \mu_C^*\,\frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial k_t^c} - \eta_k^* = 0 \qquad \text{(A1.9)}$$

$$\frac{\partial L}{\partial k_t^e} = \mu_e^*\,\frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial k_t^e} - \eta_k^* = 0 \qquad \text{(A1.10)}$$

$$\frac{\partial L}{\partial N_t^y} = \phi^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial N_t^y} - \eta_N{}^* = 0 \tag{A1.11}$$

$$\frac{\partial L}{\partial N_t^f} = \mu_f{}^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial N_t^f} - \eta_N{}^* = 0 \tag{A1.12}$$

$$\frac{\partial L}{\partial N_t^c} = \mu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial N_t^c} - \eta_N{}^* = 0 \tag{A1.13}$$

$$\frac{\partial L}{\partial N_t^e} = \mu_e{}^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial N_t^e} - \eta_N{}^* = 0 \tag{A1.14}$$

$$\frac{\partial L}{\partial L^y{}_t} = \varphi^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial L_t^y} - \eta_L{}^* = 0 \tag{A1.15}$$

$$\frac{\partial L}{\partial L_t^c} = \mu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial L_t^c} - \eta_L{}^* = 0 \tag{A1.16}$$

$$\frac{\partial L}{\partial U_t^y} = \phi^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial U_t^y} - \eta_U{}^* = 0 \tag{A1.17}$$

$$\frac{\partial L}{\partial U_t^f} = \mu_f{}^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial U_t^f} - \eta_U{}^* = 0 \tag{A1.18}$$

$$\frac{\partial L}{\partial U_t^c} = \mu_C{}^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial U_t^c} - \eta_U{}^* = 0 \tag{A1.19}$$

$$\frac{\partial L}{\partial U_t^e} = \mu_e{}^* \frac{\partial F^{*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial U_t^e} - \eta_U{}^* = 0 \tag{A1.20}$$

$$\begin{gathered} \mu_f{}^*(f_t^{d*} + f_t^{ex*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)) = 0 \\ f_t^{d*} + f_t^{ex*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f) \le 0, \mu_c{}^* \ge 0 \end{gathered} \tag{A1.21}$$

$$\begin{gathered} \mu_c{}^*(C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)) = 0 \\ C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c) \le 0, \mu_c{}^* \ge 0 \end{gathered} \tag{A1.22}$$

$$\mu_e{}^*(E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)) = 0$$
$$E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e) \le 0, \mu_e{}^* \ge 0 \qquad \text{(A1.23)}$$

$$\frac{\partial L}{\partial \eta_L} = \overline{L} - L_t^{y*} - L_t^{c*} = 0 \qquad \text{(A1.24)}$$

$$\frac{\partial L}{\partial \eta_k} = k_t{}^* - k_t^{y*} - k_t^{f*} - k_t^{c*} - k_t^{e*} = 0 \qquad \text{(A1.25)}$$

$$\frac{\partial L}{\partial \eta_N} = \overline{N} - N_t^{y*} - N_t^{f*} - N_t^{c*} - N_t^{e*} = 0 \qquad \text{(A1.26)}$$

$$\frac{\partial L}{\partial \eta_U} = U_t{}^* + E_t^{c*} - U_t^{y*} - U_t^{f*} - U_t^{c*} - U_t^{e*} = 0 \qquad \text{(A1.27)}$$

$$\frac{\partial L}{\partial Ec} = -\mu_e * + \eta_U * = 0 \qquad \text{(A1.28)}$$

$$\frac{\partial L}{\partial y^{ex}} = -\varphi_t * + p^y \eta_T * = 0 \qquad \text{(A1.29)}$$

$$\frac{\partial L}{\partial f^{ex}} = -\mu_f * + p^f \eta_T * = 0 \qquad \text{(A1.30)}$$

$$\frac{\partial L}{\partial U} = \eta_U * - p^U \eta_T * = 0 \qquad \text{(A1.31)}$$

$$\frac{\partial L}{\partial \eta_T} = p^f f_t^{ex} + p^y y_t^{ex} - p^U U_t = 0 \qquad \text{(A1.32)}$$

Appendix B

Table B.1

Results and Absolute Percentage Differences for $\tau 2$ =0.600

Variables	Production (1)	Relative price (2)	Value (3)	Value/output value (4)	Scale Value (5)	Actual data	Abs percentage difference
The composite commodity	908.0827	1.0000	908.0827		4,857,884.02	4,857,884.00	0.0000
Food from cassava	1.2212	8.3160	10.1557		54,329.08	53,759.16	0.0106
Net composite commodity for export	36.7955	1.0000	36.7955		196,841.6	1,368,025.00	0.8561
Food from cassava for export	0.7662	8.3160	6.3717		34,086.21	45,361.00	0.2485
Imported energy	21.2676	2.0297	43.1668		230,925.8	1,161,699.00	0.8012
The composite commodity production	1,539.93	1.0000	1,539.93		8,237,996.02	8,219,923.35	0.0022
Capital for the composite commodity	11,834.67	0.0850	1,005.76	0.6530	0.6530	0.6532	0.0002
Labor for the composite commodity	37.1336	11.7360	435.7990	0.2830	0.2830	0.2832	0.0008
Land for the composite commodity	20.4592	2.8602	58.5172	0.0380	0.0380	0.0380	0.0001
Energy for the composite commodity	19.7260	2.0297	40.0381	0.0260	0.0260	0.0256	0.0139
Food from cassava production	1.9874	8.3160	16.5272		88,413.77	99,120.16	0.1080
Capital for food	26.6818	0.0850	2.2675	0.1372	0.1372	0.1372	0.0000
Labor for food	0.0980	11.7360	1.1503	0.0696	0.0696	0.0696	0.0000
Raw cassava for food	1.6775	5.9113	9.9163	0.6000	0.6000	0.6000	0.0000
Energy for food	1.5732	2.0297	3.1930	0.1932	0.1932	0.1932	0.0000
Cassava production	1.7191	5.9113	10.1624		54,364.86	48,551.00	0.1197
Capital for cassava	37.0699	0.0850	3.1503	0.3100	0.3100	0.3041	0.0194
Labor for cassava	0.4676	11.7360	5.4877	0.5400	0.5400	0.5444	0.0081
Land for cassava	0.3908	2.8602	1.1179	0.1100	0.1100	0.1108	0.0072
Energy for cassava	0.2003	2.0297	0.4065	0.0400	0.0400	0.0403	0.0074
Energy production	0.2354	2.0297	0.4779		2,556.52	3,225.00	0.2073
Capital for energy	2.5305	0.0850	0.2151	0.4500	0.4500	0.4490	0.0022
Labor for energy	0.0008	11.7360	0.0096	0.0200	0.0200	0.0210	0.0476
Raw cassava for energy	0.0416	5.9113	0.2461	0.5150	0.5150	0.5150	0.0000
Energy for energy	0.0035	2.0297	0.0072	0.0150	0.0150	0.0150	0.0000
				Average Abs percentage difference			**9.8423%**

(2) is relative price where the numeraire is the composite commodity

Table B.2

Results and Absolute Percentage Differences for $\tau 2 = 0.470$

Variables	Production (1)	Relative price (2)	Value (3)	Value/output value (4)	Scale Value (5)	Actual data	Abs percentage difference
The composite commodity	910.4835	1.0000	910.4835		4,857,883.99	4,857,884.00	0.0000
Food from cassava	1.0051	10.1308	10.1825		54,328.72	53,759.16	0.0106
Net composite commodity for export	34.9488	1.0000	34.9488		186,469.13	1,368,025.00	0.8637
Food from cassava for export	0.8350	10.1308	8.4591		45,133.76	45,361.00	0.0050
Imported energy	21.3899	2.0290	43.4001		231,561.39	1,161,699.00	0.8007
The composite commodity production	1,540.48	1.0000	1,540.48		8,219,245.81	8,219,923.35	0.0001
Capital for the composite commodity	11,834.00	0.0849	1,005.09	0.6528	0.6528	0.6532	0.0005
Labor for the composite commodity	37.1702	11.7281	435.9353	0.2831	0.2831	0.2832	0.0002
Land for the composite commodity	20.5000	2.8554	58.5363	0.0380	0.0380	0.0380	0.0005
Energy for the composite commodity	19.7365	2.0290	40.0454	0.0260	0.0260	0.0256	0.0144
Food from cassava production	1.8401	10.1308	18.6416		99,462.48	99,120.16	0.0035
Capital for food	30.0900	0.0849	2.5556	0.1576	0.1576	0.1372	0.1487
Labor for food	0.1106	11.7281	1.2974	0.0800	0.0800	0.0696	0.1496
Raw cassava for food	1.4828	5.9085	8.7612	0.5403	0.5403	0.6000	0.0995
Energy for food	1.7747	2.0290	3.6009	0.2221	0.2221	0.1932	0.1494
Cassava production	1.5367	5.9085	9.0797		48,445.00	48,551.00	0.0022
Capital for cassava	33.1160	0.0849	2.8126	0.3098	0.3098	0.3041	0.0189
Labor for cassava	0.4181	11.7281	4.9031	0.5401	0.5401	0.5444	0.0078
Land for cassava	0.3498	2.8554	0.9988	0.1100	0.1100	0.1108	0.0069
Energy for cassava	0.1789	2.0290	0.3630	0.0400	0.0400	0.0403	0.0077
Energy production	0.3048	2.0290	0.6184		3,299.68	3,225.00	0.0232
Capital for energy	3.2750	0.0849	0.2782	0.4498	0.4498	0.4490	0.0018
Labor for energy	0.0011	11.7281	0.0124	0.0200	0.0200	0.0210	0.0473
Raw cassava for energy	0.0539	5.9085	0.3186	0.5152	0.5152	0.5150	0.0004
Energy for energy	0.0046	2.0290	0.0093	0.0150	0.0150	0.0150	0.0001
				Average Abs percentage difference			**9.4509%**

(2) is relative price where the numeraire is the composite commodity

Appendix C

Linear Approximation of the Differential Equations

From the current value necessary conditions,

$$\dot{k}_t = F^{y*}(.) - y_t^{d*} - y_t^{ex*} - \delta k_t^* = g(k,\lambda) \tag{1.18}$$

$$\dot{\lambda}_t = (r+\delta)\lambda_t^* - \phi_k^* = f(k,\lambda) \tag{1.17}$$

The linear approximation about stationary solution is:

$$g_k = \frac{g(k^0+dk,\lambda^0) - g(k^0,\lambda^0)}{dk} \tag{C1.1}$$

$$g_\lambda = \frac{g(k^0,\lambda^0+d\lambda) - g(k^0,\lambda^0)}{d\lambda} \tag{C1.2}$$

$$f_k = \frac{f(k^0+dk,\lambda^0) - f(k^0,\lambda^0)}{dk} \tag{C1.3}$$

$$f_\lambda = \frac{f(k^0,\lambda^0+d\lambda) - f(k^0,\lambda^0)}{d\lambda} \tag{C1.4}$$

The linear differential equations can be written as:

$$\begin{bmatrix} \dfrac{dk}{dt} \\ \dfrac{d\lambda}{dt} \end{bmatrix} = \begin{bmatrix} g_k & g_\lambda \\ f_k & f_\lambda \end{bmatrix} \cdot \begin{bmatrix} k \\ \lambda \end{bmatrix} + \begin{bmatrix} g_k & g_\lambda \\ f_k & f_\lambda \end{bmatrix} \cdot \begin{bmatrix} k_{ss} \\ \lambda_{ss} \end{bmatrix} \tag{C1.5}$$

The complementary function is;

$$k(t) = C_1 v_{11} e^{\pi_1 \cdot t} + C_2 v_{12} e^{\pi_2 \cdot t} + k_{ss} \tag{C1.6}$$

$$\lambda(t) = C_1 v_{21} e^{\pi_1 \cdot t} + C_2 v_{22} e^{\pi_2 \cdot t} + \lambda_{ss} \tag{C1.7}$$

Let k_0 = 10,401.016, find the numerical solution as:

$$M = \begin{bmatrix} g_k & g_\lambda \\ f_k & f_\lambda \end{bmatrix} = \begin{bmatrix} 0.26264 & 1449324.863 \\ 2.133658e-06 & -0.214522 \end{bmatrix}$$

$$\text{Eigen vectors (M)=} \begin{bmatrix} 0.9999 & -0.9999 \\ 1.05983e-06 & 1.38906e-06 \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \end{bmatrix}$$

$$\text{Eigen value (M)=} \begin{bmatrix} 1.79865 \\ -1.75056 \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \pi_2 \end{bmatrix}$$

For k_0 = 10,401.016, k_{ss} = 11,901.016, and λ_{ss} = 0.9172

Solve equation (C1.6) and (C1.7) for C_1 and C_2, we obtained C_1 =0, C_2 =1450.016

Thus, the general solution for k_t and λ_t are;

$$k(t) = 1,450.016 \cdot (-0.999) e^{-1.75056 \cdot t} + 11,901.016 \tag{C1.8}$$

$$\lambda(t) = 1,450.016 \cdot (1.38e-06) e^{-1.75056 \cdot t} + 0.9172 \tag{C1.9}$$

Runke-Kutta Reverses Shooting

The method of second order Runke-Kutta:

Suppose $\frac{d\lambda}{dk} = G(k_t, \lambda_t)$, h is step size

$$S_1 = h \cdot G(k_n, \lambda_n) \tag{C1.10}$$

$$S_2 = h \cdot G(k_n + 0.5h, \lambda_n + 0.5S_1) \tag{C1.11}$$

$$k_{t+1} = k_t + h \tag{C1.12}$$

$$\lambda_{t+1} = \lambda_t + S_2 \tag{C1.13}$$

The procedure to generate the set of solutions is to consider step size h for moving from the chosen point (k_n, λ_n) and then using equation (C1.10)-(C1.13) to generate k_{t+1} and λ_{t+1}. Repeat the step of computation above to generate a solution time path.

Capital Stock Policy Function

An approximation of the capital stock policy function $K(\lambda(t))$ is calculated by using equations (1.18) and (1.17);

$$\frac{d\lambda_t}{dt} = f(k_t, \lambda_t) \qquad \text{(C1.14)}$$

$$\frac{dk_t}{dt} = g(k_t, \lambda_t) \qquad \text{(C1.15)}$$

Suppose; $k_t = K(\lambda_t)$

Thus, we can write $\frac{dk_t}{dt} = K'(\lambda_t)\frac{d\lambda_t}{dt}$ or, $K'(\lambda(t)) = \frac{\dot{k}}{\dot{\lambda}} = \frac{g(k_t, \lambda_t)}{f(k_t, \lambda_t)}$ (C1.16)

ESSAY 2: A DYNAMIC GENERAL EQUILIBRIUM MODEL OF ENERGY CROP PRODUCTION AND INTERNATIONAL TRADE

Introduction

An increase in bio fuel production is significantly raising the price of food. A study of UN-Energy revealed that a large scale production of bio fuels will result in higher food prices for poor consumers around the world (UN-Energy, 2007). The high food prices affected developing countries by increasing the price of food imports by10 percent in 2006 (Rosen and Shapouri, 2008). This resulted in a decrease in total imports for many countries. The higher food prices and a reduction in food imports adversely affected food security of these countries. The ERS food assessment model indicated that an annual increase of one percent in food prices from 2007-2016 will result in a food gap (the amount of food needed to increase consumption of all income groups to meet their requirement) of 25.2 million tons (Rosen and Shapouri, 2008). Especially in food import dependent countries, rising food prices imply high food insecurity.

The rising energy crop production by developing countries benefits the agriculture sector, since most of their population depends on employment and income from agriculture production. The countries that produce bio fuel receive benefit both from higher food prices and reduced fuel prices. It results in reducing the import of fossil fuel and the export of food. In contrast, the population in those countries, especially low income countries, also suffers from high domestic food prices and reduced food availability. The decision of whether to use energy crops for food or for bio fuel is a controversial issue that every country needs to be concerned about. Bio fuel production affects food consumption as well as the welfare of the country. The rising use of crops for bio fuel results in the lower use of those crops for food. The food consumption of the countries tends to fall and implies a reduction in their welfare. The policy in each country needs to balance both the food security issue and the fuel dependent issue to maintain well being in their population.

In this essay, we study an economy that produce energy crop that can be used in production of food and energy. The objective of the study is to understand the effects of trade and of the changes in land supply, labor supply, and imported energy price on bio fuel and food productions as well as on the welfare. We construct two models, in a dynamic general equilibrium set-up: a closed and an open economy model. The results of the models are compared to understand the effects of international trade. The models are calibrated by using Thailand data and by focusing on cassava as an energy crop. As a low-income country with rapidly expanding ethanol production, Thailand is chosen to be a case study to explain the change in the country's welfare when it has to balance the production of bio fuel and food.

This paper is organized as follows: The next section reviews the literature. In section III, we present the closed economy model and the open economy model. Section IV is allocated to data and parameters. We outline our analysis and results in section V where the closed and open economy models are simulated using Thailand data. In addition, we present some comparative dynamic results. Section VI concludes the essay.

Literature Review

Various studies have examined the impacts of ethanol production on the change in land use and scarcity of land. Chakravorty, Magne, and Moreaux (2007) applied the dynamic model of food and clean energy to allocate land to produce food and fuel. They found that the scarcity of land resulted in shifting from farming for food to farming for fuel. Westcott (2007) presented the results from USDA's long-term projections that the expansion areas of planting corn for ethanol come from soybean. Soybean directly competed with corn on amount of land use. In the next five to six years, corn planting areas will increase while soybean acreages will decline. Susanto, Rosson, and Hudson (2008) analyzed the impacts of ethanol production on southern states of the United States. They used regression analysis to describe the land use for the four main crops of southern agriculture: corn, cotton, soybeans, and wheat. The results showed that a significant increase in corn prices relative to other crop prices resulted in an increase in corn acreages and in a reduction of acreages for other crops. Malcolm, Aillery, and Weinberg (2009) studied the effects of the EISA 2007 (The Energy Independence and Security Act) targets for the United States bio fuel production on regional agriculture production. They explained that land for bio fuel production comes from two sources: acreage not currently in production and acreage shifted from other crops. They projected that by 2015 and when the targets are met, total crop acreages will expand by 1.6 percent with corn acreage increasing by 3.5 percent. Dicks et al. (2009) studied the land use implications of expanding bio fuel demand for the targets of the EISA 2007. The estimations were examined by POLYSYS model and a general equilibrium model. They concluded that land use for major crops such as paddy rice, wheat, fruits and vegetables, oil seeds, sugar cane, etc will decline. In contrast, the price of land will increase about 17.2 % from the base and all crop prices will increase more than 2 % including livestock and animal products.

Few studies highlight the impacts of ethanol production on employment and the agriculture sector. Peters (2007) studied the effects of ethanol expansion on local economy. He showed that an increase in a 100-million-gallon-per-year - ethanol plant in rural Nebraska County had directly created 168 jobs including jobs in farming, manufacturing, transportation and warehousing, retail trade, administrative, food services, and others. Neuwahl, Loschel, Mongelli, and Delgado (2008) analyzed the employment impacts of the European Union bio fuel policy by using input-output framework to simulate scenarios for the year 2020 targets. They indicated that the bio fuel targets of up to a 15 percent share of substitution would not cause adverse employment effects. Smeets et al. (2008) studied the sustainability of Brazilian ethanol in the state of Sao Paulo (Brazil). The study evaluated the socio-economical impacts of ethanol production from sugar cane on various concerns. They found that the production of sugar cane and ethanol were the largest sources of employment. The main effects of ethanol production on employment were the increase in employment in sugar cane and ethanol production sectors. The indirect effects were the employment generated in industries that served as intermediaries between the sugar cane and ethanol production sectors, while there were some employment losses from the induced effects such as a decline in competing crop production. Blanco and Isenhouer (2010) investigated the impact of ethanol production in the Corn Belt states (Iowa, Indiana, Illinois, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin) on employment and wages. They modified the regression version of Hanson's model (Hanson, 2001) to estimate average employment and average real wage for each state. The results showed that ethanol production had a small, positive effect on employment and wages. They explained that the ethanol industry was not labor intensive and corn production was likely to be capital intensive in the United States.

The relative price change is one of the key factors that affect ethanol and fuel crop production. When the price of fuel crops is high compared to other crops, it results in shifting land and employment to produce that fuel crop. Some studies discuss the effects of change in relative prices on the agriculture sector. Elobeid and Hart (2007) concluded that the ethanol expansion resulted in an increase in commodity prices and affected the global market. They showed that an increase in world commodity prices raised the cost of food around the world. It affected food security, especially in developing countries. Kim, Schaible, and Daberkow (2010) studied the effects of the U.S. bio fuel policies on the energy market. They employed a profit maximization model to describe the relative impacts of tax credits and blending mandates on equilibrium prices of energy. They found that prices of all fuel decreased when bio fuel tax credit increased and such prices increased when the rate of blending mandate increased. In addition, their results indicated that a blending mandate was a more effective policy when the marginal rate of substitution between the blending mandate and the tax credit was greater. Another study on bio fuel policy in the United States examined the effects of price changes on trade.

Devadoss and Kuffel (2010) also studied the impacts of the tax credit and mandate policies of the U.S. on ethanol trade between the U.S. and Brazil. They estimated the optimal import subsidy and import tariff value by using a horizontally related ethanol gasoline partial equilibrium model of the United States, Brazil, and the rest of the world. The results indicated that the United States should apply import subsidies instead of using import tariffs because this would help to increase competition and bring efficiency, innovation and production to the global market.

The literature has examined the impact of increasing ethanol production on various aspects of the economy such as land use, labor supply, and imported energy prices. Through these aspects, the implications of the changes in the economy due to ethanol production are provided. I contribute to the literature by developing a framework for analyzing the effects of international trade on bio fuel production. We also study the impacts of changes in land supply, labor supply, and imported energy prices on consumption, production, and allocation of economic resources. In the next section, we develop our theoretical framework.

Theoretical Framework

A dynamic general equilibrium optimal control model of energy crop is developed in the previous essay (Energy Crop for Sustainable Development). The basic model in that essay was applied to analyze the Thai economy to find the stationary state of the economy and to describe the optimal time path. In the current essay, the model is extended to study the effects of trade and the changes in labor supply, land supply, and imported energy price. We consider two models, a closed economy model and an open economy model. The models are considered as small economy model. The objective of using two types of models is to determine the values of all relevant variables of the model in continuous time and to compare the difference between the economies with and without international trade. The social planning objective is to maximize the sum of the discounted utility function of society in both closed and open economy models under various constraints over the infinite time horizon. The utility function in each model at any given time depends on domestic consumption of food (where “food” in this study is defined as food produced from cassava) and composite commodity.

Closed Economy Model

A closed economy model was constructed without international trade that assumes that domestic production and consumption are equal. The production of a commodity is equal to its domestic consumption for all goods. In addition, we assume that there is only one source of energy in the economy, implying that the economy has to produce energy crops large enough to supply all energy demands in the economy.

The continuous time social planner problem for the closed economy model is given by equation (2.1)-(2.11). The objective of the model (2.1) is to maximize W over the infinite time horizon subject to the constraints (2.2) to (2.11).

The objective function is:

$$W = \int_0^\infty e^{-rt} u(y_t^d, f_t^d) dt \tag{2.1}$$

The constraints for the problem are (2.2-2.11):

$$\frac{dk_t}{dt} = I_t - \delta k_t \tag{2.2}$$

$$y_t^d + I_t - F_y(k_t^y, N_t^y, L_t^y, U_t^y) = 0 \qquad (2.3)$$

$$f_t^d - F_f(k_t^f, N_t^f, C_t^f, U_t^f) \leq 0 \qquad (2.4)$$

$$C_t^f + C_t^e - F_c(k_t^c, N_t^c, L_t^c, U_t^c) \leq 0 \qquad (2.5)$$

$$E_t^c - F_e(k_t^e, N_t^e, C_t^e, U_t^e) \leq 0 \qquad (2.6)$$

$$k_t - k_t^y - k_t^f - k_t^c - k_t^e = 0 \qquad (2.7)$$

$$\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e = 0 \qquad (2.8)$$

$$\overline{L} - L_t^y - L_t^c = 0 \qquad (2.9)$$

$$E_t^c - U_t^y - U_t^f - U_t^c - U_t^e = 0 \qquad (2.10)$$

$$k_0 = k^0 \qquad (2.11)$$

where all our notations are presented in Table 2.1, which also describes all above constraints.

Open Economy Model

The continuous time social planner problem for the open economy has the same structure as the closed economy, but it is augmented by having a trade balance equation and export-import variables. We also assume that the economy has two exported commodities, food and the composite good, and one imported good, energy. It implies that the economy can import energy to satisfy the demands in the economy and it can export composite commodity and food if it has an excess supply of them in the economy.

The continuous time social planner problem for the open economy model is to maximize (2.12) subject to (2.13)-(2.23).

The objective function is:

$$W = \int_0^\infty e^{-rt} u(y_t^d, f_t^d) dt \tag{2.12}$$

The constraints for the problem are (2.13- 2.23):

$$\frac{dk_t}{dt} = I_t - \delta k_t \tag{2 .13}$$

$$y_t^d + y_t^{ex} + I_t - F_y(k_t^y, N_t^y, L_t^y, U_t^y) = 0 \tag{2 .14}$$

$$f_t^d + f_t^{ex} - F_f(k_t^f, N_t^f, C_t^f, U_t^f) \le 0 \tag{2.15}$$

$$C_t^f + C_t^e - F_c(k_t^c, N_t^c, L_t^c, U_t^c) \le 0 \tag{2.16}$$

$$E_t^c - F_e(k_t^e, N_t^e, C_t^e, U_t^e) \le 0 \tag{2.17}$$

$$k_t - k_t^y - k_t^f - k_t^c - k_t^e = 0 \tag{2.18}$$

$$\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e = 0 \tag{2.19}$$

$$\overline{L} - L_t^y - L_t^c = 0 \tag{2.20}$$

$$U_t + E_t^c - U_t^y - U_t^f - U_t^c - U_t^e = 0 \tag{2.21}$$

$$k_0 = k^0 \tag{2.22}$$

$$p^f f_t^{ex} + p^y y_t^{ex} - p^u U_t = 0 \tag{2.23}$$

where Table 2.1 describes the above constraints.

Table 2.1

Constraints Descriptions and Notations

Equations	Descriptions
(2.2) and (2.13)	$\frac{dk_t}{dt} = I_t - \delta k_t$ is the net increase in the stock of physical capital at a point in time which equals the gross investment (I_t) less its depreciation (δk_t), where δ is the depreciation rate and k_t is the stock of physical capital.

(2.3) and (2.14)	The production function for the composite commodity ($F_y(k_t^y, N_t^y, L_t^y, U_t^y)$), where $k_t^y, N_t^y, L_t^y,$ and U_t^y are capital, labor, land, and energy, respectively.
	For (2A.3), the production function is expected to equal the sum of its domestic consumption (y_t^d), and gross investment (I_t).
	For (2B.3), the production is expected to equal the sum of its domestic consumption (y_t^d), its export (y_t^{ex}), and gross investment (I_t).

(2.4) and (2.15)	The production function for food from cassava ($F_f(k_t^f, N_t^f, C_t^f, U_t^f)$) where C_t^f is the raw cassava which is used as feedstock for producing food.
	For (2A.4), the food production is expected to be greater or equal to its domestic consumption (f_t^d).
	For (2B.4), the food production is expected to be greater or equal to its domestic consumption (f_t^d) plus its export (f_t^{ex}).

(2.5) and (2.16)	The production function for raw cassava ($F_c(k_t^c, N_t^c, L_t^c, U_t^c)$) is greater than or equal to the sum of raw cassava used in food production (C_t^f) and raw cassava used in energy production (C_t^e).

Table 2.1

Continued

Equations	Descriptions
(2.6) and (2.17)	The production function for energy produced from cassava ($F_e(k_t^e, N_t^e, C_t^e, U_t^e)$) is greater than or equal to energy produced from cassava (E_t^c).
(2.7) and (2.18)	The full employment constraint of capital used, that is, total capital stock equals the sum of the stock of capital used in composite commodity production (k_t^y), in food production (k_t^f), in raw cassava production (k_t^c) and in energy production (k_t^e).
(2.8) and (2.19)	The total labor used in all industries, which is the sum of labor used in composite commodity production (N_t^y), labor used in food production (N_t^f), labor used in raw cassava production (N_t^c), and labor used in energy from cassava production (N_t^e), equals total labor available in economy ($\overline{N}$).
(2.9) and (2.20)	This is the total land available in economy ($\overline{L}$), which is the sum of land used in composite commodity production (L_t^y) and land used in raw cassava production (L_t^c).

(2.10) and (2.21)	This is total energy constraint.
	For (2A.10), the supply of energy is only that produced from cassava (E_t^c) and it is equal to the sum of energy demand, which includes energy used in composite commodity production (U_t^y), energy used in food production (U_t^f), energy used in raw cassava production (U_t^c) and energy used in energy produced from cassava production (U_t^e).
	For (2B.10), energy supply is the sum of total energy import (U_t) plus energy from cassava, and it is equal to all energy demand.

(2.11) and (2.22)	This is the given initial value of stock of capital

Table 2.1

Continued

Equations	Descriptions
(2.23)	This is the trade balance equation where: $p^f f_t^{ex}$ is the value of food export where p^f is the relative price between food price and composite commodity price, and f_t^{ex} is the food export quantity. $p^y y_t^{ex}$ is the net value of composite commodity export. We consider the term of $p^y y_t^{ex}$ as the net value of composite commodity export for covering the rest of the economy total exports minus the value of its total imports. p^y is a numeraire price and equals to one, and y_t^{ex} is the net export quantity of composite commodity (composite commodity export minus its import). $p^u U_t$ is the value of energy import. p^u is the relative price of energy in units of composite commodity, and U_t is the energy import quantity.

The present value Hamiltonian, the present value Largrangian, and the current value necessary conditions for the problems defined in (2.1)-(2.11) are presented in Appendix A for the closed economy model, and those values for the problem defined in (2.12)-(2.23) are presented in Appendix B for the open economy model. The optimal sets of solutions for closed economy model (2.1)-(2.11) and for open economy model (2.12)-(2.23) will be derived by applying the maximum principle as a tool.

Models with Cobb-Douglas Function

We assume Cobb-Douglas function as the utility function and the production functions in the models. The utility functions in (2.1) and (2.12) have the same structure and variables. Thus, the utility functions in (2.1) and (2.12) can be specified in the form of Cobb-Douglas function as equation (2.24).

$$W = \int_0^T e^{-rt}[(y_t^d)^\alpha \cdot (f_t^d)^\beta]dt \tag{2.24}$$

The production functions for the closed economy model in equations (2.3)-(2.6) can be specified in Cobb-Douglas functional form as equations (2.25), (2.26), (2.27), (2.28), respectively.

For the closed economy model,

$$y_t^d + I_t - \left[(k_t^y)^{\gamma 1} \cdot (N_t^y)^{\rho 1} \cdot (L_t^y)^{\sigma 1} \cdot (U_t^y)^{\delta 1}\right] = 0 \tag{2.25}$$

$$f_t^d - \left[(k_t^f)^{\gamma 2} \cdot (N_t^f)^{\rho 2} \cdot (C_t^f)^{\tau 2} \cdot (U_t^f)^{\delta 2}\right] \leq 0 \tag{2.26}$$

$$C_t^f + C_t^e - \left[(k_t^c)^{\gamma 3} \cdot (N_t^c)^{\rho 3} \cdot (L_t^c)^{\sigma 3} \cdot (U_t^c)^{\delta 3}\right] \leq 0 \tag{2.27}$$

$$E_t^c - \left[(k_t^e)^{\gamma 4} \cdot (N_t^e)^{\rho 4} \cdot (C_t^e)^{\tau 4} \cdot (U_t^e)^{\delta 4}\right] \leq 0 \tag{2.28}$$

The production functions for the open economy model have the same specification as the closed economy model except equation (2.25) and (2.26) are specified as equation (2.27) and (2.28) instead:

$$y_t^d + y_t^{ex} + I_t - \left[(k_t^y)^{\gamma 1} \cdot (N_t^y)^{\rho 1} \cdot (L_t^y)^{\sigma 1} \cdot (U_t^y)^{\delta 1}\right] = 0 \qquad (2.27)$$

$$f_t^d + f_t^{ex} - \left[(k_t^f)^{\gamma 2} \cdot (N_t^f)^{\rho 2} \cdot (C_t^f)^{\tau 2} \cdot (U_t^f)^{\delta 2}\right] \leq 0 \qquad (2.28)$$

where α and β are the preference parameters of composite commodity and of food respectively. $\gamma 1$-$\gamma 4$ are output elasticity of capital for composite commodity, for food, for cassava, and for utilized energy, respectively. $\rho 1$-$\rho 4$ are output elasticity of labor for composite commodity, for food, for cassava, and for utilized energy, respectively. $\sigma 1$ and $\sigma 3$ are output elasticity of land for composite commodity and for cassava. $\tau 2$ and $\tau 4$ are output elasticity of cassava for food and for utilized energy. And $\delta 1$-$\delta 4$ are output elasticity of utilized energy for composite commodity, for food, for cassava, and for utilized energy, respectively.

Data and Parameters

We apply our closed and open economy models to the Thai economy by using national yearly data for 2007-2008. We also use relevant estimated parameters obtained from the literature, which are presented in Table 2.2. The preference parameters of composite commodity and food from cassava are estimated by using its expenditure share in the total expenditure, which can be obtained from of Office of National Economic and Social Development Board.

The output elasticity can be obtained by using factor share of the output. The data for the factor shares in composite commodity production is obtained from the Office of National Economics and Social Development Board (2009). The data for factor shares in food production is obtained from the research study of the Export-Import Bank of Thailand (2008). The data for factor shares in raw cassava production is obtained from the Office of Agriculture Economics (2009). And the data of factor shares in ethanol production from cassava is obtained from Yoosin and Sorapipatana (2007).

The parameter $\bar{L}$ is the total land area available for production and it is set to 20.82 million hectares. This data uses total agricultural land available for all agricultural production and obtained from the Ministry of Agriculture and Cooperative. The parameter $\overline{N}$ is the total labor available in the economy, and it is set to be 37.7 million persons, obtained from the National Economic and Social Development Board (2009).

Table 2.2

Data and Parameter Substitutions

Function	Parameter descriptions	Symbol	Observed value
Utility function	Preference parameter of composite commodity	α	0.9889
	Preference parameter of food	β	0.01106
Composite commodity production function	Output elasticity of capital	γ_1	0.653
	Output elasticity of labor	ρ_1	0.2832
	Output elasticity of land	σ_1	0.038
	Output elasticity of energy	δ_1	0.02564
Food production function	Output elasticity of capital	γ_2	0.1372
	Output elasticity of labor	ρ_2	0.0696
	Output elasticity of raw cassava	τ_2	0.470[a]
	Output elasticity of energy	δ_2	0.1932
Raw cassava production function	Output elasticity of capital	γ_3	0.3041
	Output elasticity of labor	ρ_3	0.5444
	Output elasticity of land	σ_3	0.1108
	Output elasticity of energy	δ_3	0.0403
Energy from cassava production function	Output elasticity of capital	γ_4	0.449
	Output elasticity of labor	ρ_4	0.0079
	Output elasticity of raw cassava	τ_4	0.5415
	Output elasticity of energy	δ_4	0.00151
	Total land area available for production	$\overline{L}$	20.82 million hectares
	Total labor available in economy	$\overline{N}$	37.7 million persons
	Interest rate	r	3.5%
	Depreciation rate	δ	5%

[a] the parameter value which is set to reduce the absolute percentage difference value (the description is shown in Essay 1: Energy Crop for Sustainable Development)

The interest rate and depreciation rate are assigned to be 3.5% and 5%, respectively. The interest rate is obtained from World Fact Book (Central Intelligence Agency, 2010). In this study, the discount rate or interest rate is set to 3.5%, the average for 2007-2008. The depreciation rate used is from Tanboon (2008). In this study, the depreciation rate is calculated by using Tanboon's concept, which is used for the structural model for the Bank of Thailand policy analysis. The average annual depreciation rate of the real sector (agriculture sector and industrial sector) in 2007 is set to 5%.

Results

The dynamic general equilibrium optimal control model for energy crop, with infinite time horizon has the ability to generate optimal value for all variables in the model under the maximum principle. As stated earlier, Cobb-Douglas functional forms are used to calibrate this model using Thailand data by employing cassava as an energy crop. The baseline models present the sets of optimal solutions in stationary states for both closed and open economies. The three hypothetical scenarios are introduced to the model to determine the impacts of the changes in factor endowments and imported price of energy.

The Effect of Trade

The baseline models for a closed economy model stated by equations (2.1)-(2.11) and an open economy model expressing equations (2.12)-(2.23) are calibrated with Thailand data by highlighting cassava as the energy crop. A closed economy model assumes that the domestic utilized energy in the economy can be produced only from the energy crop. The open economy model allows composite commodity and food as export goods, and energy as an import good. The models assume composite commodity as the numeraire good. Thus the prices of all goods in the economy are shown in relative prices in terms of the composite commodity. The welfare is computed from the utility function of the domestic consumption of composite commodity and food.

The results of both models are presented in Table 2.3. Each model is calibrated using the same set of data. The sets of optimal solutions of closed and open economy models are presented in quantities and relative shadow prices for each variable. In Table 2.3, under autarky, the consumption of composite commodity is 909.125 and the consumption of food is 1.086; whereas in the open economy, the consumption of composite commodity is higher at 910.484 and the consumption of food is lower at 1.005. In a closed economy, there is higher production of raw cassava and energy than in an open economy because the economy cannot import energy, and raw cassava is the only source of energy for all sectors. We notice that in an open economy, all factors are allocated to produce more composite commodity and food. As expected from the neoclassical trade theory, the welfare level is higher under free trade compared with autarky (844.44 relative to 843.91).

With international trade, relative energy price or the imported price is less than it is in the closed economy. In contrast, relative food price or the exported price of food is higher than it is in the closed economy. The relative price of raw cassava in the open economy is lower than it is in the closed economy. Comparing the two sets of relative factor prices, in the open economy, the relative factor price of labor is higher, the relative price of capital is almost the same, and the relative price of land and the relative price of energy are lower than they are in the closed economy.

Table 2.3

Baseline Stationary State Solutions for Closed and Open Economy Models

	Quantities		Relative shadow prices	
Variables	Closed economy	Open economy	Closed economy	Open economy
Consumption				
Composite commodity	909.125	910.484	1.000	1.000
Food from cassava	1.086	1.005	9.364	10.131
Net composite commodity for export	0	34.949	1.000	1.000
Food from cassava for export	0	0.835	9.364	10.131
Imported energy	0	21.390	2.030	2.029
Production and factor use				
Composite commodity production	1503.789	1540.483	1.000	1.000
Capital	11552	11834	0.085	0.085
Labor	36.331	37.170	11.714	11.728
Land	19.827	20.500	2.876	2.855
Energy	19.263	19.737	2.030	2.029
Food from cassava production	1.086	1.840	9.364	10.131
Capital	16.411	30.090	0.085	0.085
Labor	0.060	0.111	11.714	11.728
Raw cassava	0.808	1.483	5.911	5.909
Energy	0.968	1.775	2.030	2.029
Raw cassava production	4.536	1.537	5.911	5.909
Capital	97.773	33.116	0.085	0.085
Labor	1.236	0.418	11.714	11.728
Land	1.023	0.350	2.876	2.855
Energy	0.528	0.179	2.030	2.029
Energy production from cassava	21.076	0.305	2.0296	2.0290
Capital	226.465	3.275	0.085	0.085
Labor	0.070	0.001	11.714	11.728
Raw cassava	3.727	0.054	5.911	5.909
Energy	0.316	0.005	2.030	2.029
Utility	**843.910**	**844.436**		

Both sets of solutions in Table 2.3 indicate that the welfare of society in the open economy is higher than it is in the closed economy. In the open economy, the society consumes more of composite commodity and less on food. In addition, food and composite commodity are produced more for export, while energy production is reduced and is imported. The open economy reallocates all factors (capital, land, labor, and energy) to produce more composite commodity and food. Due to the assumption for the closed economy that energy from the energy crop is the only source of energy use in the economy, the solutions in the closed economy for raw cassava and energy production quantities are significantly higher than they are in the open economy. In this study, the objective of comparing closed and open economy models is to investigate and study how an economy adjusts its consumption, production, and factor allocation when it is open. The sets of solutions do not completely represent the real economy in Thailand. In the next subsection, these models are used with three alternative scenarios to determine the impacts of the changes in factor endowments and the price of energy.

The Effects of Labor Supply Increase

In this section, we analyze the departures from baseline models. The changes in labor supply, land supply, and imported energy prices are introduced to the models to determine how the economy will react and adjust its resources, consumption, and production, to a new stationary state level. The baseline models are employed in the rest of this essay to simulate and conduct comparative dynamic analysis.

Scenario 1 posits a hypothetical increase in labor supply by 10 percent in Thailand. The rationale behind this scenario is the naturally increasing population in the long run. The baseline models assume a fixed labor supply in the economy. Thus, this hypothetical scenario extends the baseline models to capture the effects of a change in the supply of labor.[1]

We introduce a 10 percent increase in labor supply to the models. $\overline{N}$ in baseline models is 37.7 million persons and is increased to 41.47 million persons. The results for the closed and open economy models are shown in Table 2.4. The change in labor supply causes the overall welfare to increase, both under autarky and free trade, at autarky all resources are allocated to produce more raw cassava and energy compared to the trading equilibrium under both levels of labor supply. That is, the allocation of all resources in the open economy is emphasizing the composite commodity and food production. An increase in labor supply reduces relative factor prices of labor for both the closed and open economies. For the open economy, the relative price of food for export and energy for import increase compared to the baseline model.

Focusing on the effect of increase in labor endowments to the factor rewards, we found that each factor in production is rewarded according to its relative shadow price. Comparing between baseline model and scenario 1, the factor reward for capital is equal to its in baseline model, the factor reward for labor is lower, while the factor reward for land, energy, and raw cassava are higher than they are in baseline model.

These results indicate that the increase in labor supply leads to increased factor use (capital, raw cassava, energy) except for land, which is fixed.

[1] Note that we have used aggregate utility function à la Samuelson (Samuelson, 1956). This aggregate utility function is widely used in international trade.

Table 2.4

Stationary State Solutions for the Effect of Labor Supply Increase

Variables	Quantities		Relative shadow prices	
	Closed economy	Open economy	Closed economy	Open economy
Consumption				
Composite commodity	988.705	990.072	1.000	1.000
Food from cassava	1.167	1.083	9.476	10.225
Net composite commodity for export	0	35.349	1.000	1.000
Food from cassava for export	0	0.860	9.476	10.225
Imported energy	0	21.721	2.033	2.032
Production and factor use				
Composite commodity production	1635.423	1672.476	1.000	1.000
Capital	12563.897	12848.548	0.085	0.085
Labor	39.964	40.821	11.581	11.595
Land	19.827	20.452	3.134	3.107
Energy	20.920	21.397	2.033	2.032
Food from cassava production	1.167	1.943	9.476	10.225
Capital	17.848	32.066	0.085	0.085
Labor	0.066	0.119	11.581	11.595
Raw cassava	0.877	1.575	5.929	5.927
Energy	1.051	1.889	2.033	2.032
Raw cassava production	4.917	1.895	5.929	5.927
Capital	106.332	40.973	0.085	0.085
Labor	1.359	0.523	11.581	11.595
Land	1.023	0.398	3.134	3.107
Energy	0.574	0.221	2.033	2.032
Energy production	22.888	1.813	2.033	2.032
Capital	246.289	19.507	0.085	0.085
Labor	0.080	0.006	11.581	11.595
Raw cassava	4.041	0.320	5.929	5.927
Energy	0.343	0.027	2.033	2.032
Utility	**917.662**	**918.158**		

Both the closed and open economies produce more composite commodity, food, raw cassava, and energy and consume more composite goods and food than they do in the baseline models. The open economy has slightly higher export and import quantities than the baseline open model. It also produces more domestic energy. The relative price of imported energy in the open model is slightly lower than its price in the closed economy. The utility of society increases a lot, while the relative prices of all goods only slightly increase.

The Effects of Increase in Land Supply

Scenario 2 posits a hypothetical 10 percent increase in land supply in Thailand. In contrast to the baseline scenario, which assumes fixed land available, under scenario 2, the models are examined with a 10 percent increase in land supply to investigate how that would impact consumption, production, allocation, and country welfare both with and without international trade.

In this section we study a hypothetical increase in land supply of 10 percent in Thailand under both autarky and free trade scenarios. The available land ($\bar{L}$) of 20.82 million hectares in the baseline models is increased to 22.902 hectares in this scenario. The results for both closed and open economy models are presented in Table 2.5. An increase in land supply leads to a higher welfare. All production and consumption for both models are higher than they are in the baseline model. An increase in land supply results in lower relative prices of raw cassava and energy compared to the baseline model.

Table 2.5

Stationary State Solutions for the Effect of Land Supply Increase

Variables	Quantities		Relative shadow prices	
	Closed economy	Open economy	Closed economy	Open economy
Consumption				
Composite commodity	919.545	920.709	1.000	1.000
Food from cassava	1.098	1.016	9.369	10.133
Net composite commodity for export	0	30.748	1.000	1.000
Food from cassava for export	0	0.840	9.369	10.133
Imported energy	0	19.373	2.0270	2.0265
Production and factor use				
Composite commodity production	1521.026	1553.032	1.000	1.000
Capital	11685.055	11930.942	0.085	0.085
Labor	36.331	37.054	11.848	11.861
Land	21.810	22.451	2.650	2.629
Energy	19.512	19.925	2.027	2.0265
Food from cassava production	1.098	1.856	9.369	10.133
Capital	16.599	30.359	0.085	0.085
Labor	0.060	0.110	11.848	11.861
Raw cassava	0.820	1.501	5.892	5.890
Energy	0.980	1.793	2.027	2.0265
Raw cassava production	4.602	1.964	5.892	5.890
Capital	98.894	42.186	0.085	0.085
Labor	1.236	0.527	11.848	11.861
Land	1.125	0.484	2.650	2.629
Energy	0.535	0.228	2.027	2.0265
Energy production	21.347	2.613	2.027	2.027
Capital	229.061	28.035	0.085	0.085
Labor	0.073	0.009	11.848	11.861
Raw cassava	3.782	0.463	5.892	5.890
Energy	0.320	0.039	2.027	2.0265
Utility	**853.578**	**853.918**		

Focusing on the open economy model, we notice that the trade quantities for all export and import are less than they are in the baseline model. The main reason is the significant increase in domestic energy production and lower imported energy price compared to the baseline model, which substitutes a high volume of energy import.

A comparison of results between the closed and open economy models shows that in the closed economy, the allocation of all factors to produce raw cassava and energy is significantly higher. Under free trade, more composite commodity and food are produced, and as a result, welfare increases.

The Effects of an Increase in Imported Energy Price

Scenario 3 posits a hypothetical increase in relative price of imported energy in Thailand. It is possible that an increase in relative prices will occur in the real economy. The changes in relative prices have different effects on adjusting the economy to the stationary state level. This hypothetical scenario is brought in to the open economy baseline model to compare the impacts of changes in import price to the baseline scenario.

In this section we shock the economy with a 0.1 percent increase in relative price of imported energy. The price changes from 2.029 in the baseline model to 2.0334 in this scenario. The results are shown in Table 2.7. The effects of this change reverse the status of the economy from that of exporter of composite commodity to one of importer of goods, while becoming an exporter of energy. The higher world energy price induces the economy to largely increase its production of raw cassava and energy.

Table 2.7

Stationary State Solutions for the Effect of Imported Energy Price Increase

Variables	Quantities		Relative shadow prices	
	Baseline open model	0.1% increase in relative energy price	Baseline model	0.1% increase in relative energy price
Consumption				
Composite commodity	910.484	899.503	1.000	1.000
Food from cassava	1.005	0.993	10.131	10.131
Net composite commodity for export	34.949	-212.540	1.000	1.000
Food from cassava for export	0.835	0.838	10.131	10.131
Imported energy	21.390	-100.351	2.0290	**2.0334**
Production and factor use				
Composite commodity production	1540.483	1265.748	1.000	1.000
Capital	11834.0	9723.92	0.085	0.085
Labor	37.170	30.790	11.728	11.634
Land	20.500	15.869	2.855	3.031
Energy	19.737	16.200	2.029	2.0314
Food from cassava production	1.840	1.831	10.131	10.131
Capital	30.090	29.934	0.085	0.085
Labor	0.111	0.111	11.728	11.634
Raw cassava	1.483	1.472	5.909	5.922
Energy	1.775	1.764	2.029	2.0314
Raw cassava production	1.537	23.177	5.909	5.922
Capital	33.116	500.553	0.085	0.085
Labor	0.418	6.370	11.728	11.634
Land	0.350	4.981	2.855	3.031
Energy	0.179	2.703	2.029	2.0314
Energy production	0.305	122.860	2.029	2.031
Capital	3.275	1321.290	0.085	0.085
Labor	0.001	0.429	11.728	11.634
Raw cassava	0.054	21.705	5.909	5.922
Energy	0.005	1.843	2.029	2.0314
Utility	**844.436**	**834.253**		

The economy exports a large volume of energy while importing a large volume of composite commodity at the same time. The export of food slightly increases with the same relative price of food for export. The welfare declines from its level in the baseline model. All factors, especially capital and land, are allocated to produce more raw cassava and energy than they are in the baseline model. This indicates that when the world price of energy is high enough and the economy has ability to produce sufficient food and energy, the allocation of raw cassava for producing food or energy is dependent on their prices.

Conclusion

In this essay, we extended our dynamic general equilibrium model to study the effect of trade. The dynamic general equilibrium optimal control model of energy crop in the prior essay is used to construct two baseline models: a closed economy model and an open economy model. We also conduct some interesting comparative dynamics. The changes in supply of labor, supply of land, and imported energy price are assumed in the models in each scenario. The models of a closed and an open economy are calibrated with Thailand data by highlighting cassava as an energy crop to find the optimal set of solutions. The study focuses on the effects of the changes on an adjustment of resource allocation in the economy and compares the welfare difference between economies with and without international trade.

The results of the baseline models and scenarios analysis indicate that when an economy is open : (1) it has a higher welfare level with lower energy price compared to a closed economy; (2) as a result of trade, all resources in the economy are re-allocated to produce more food rather than energy; (3) when labor supply increases, the economy has higher overall utility; (4) when available land for production increases, welfare of society increases while the trade volume declines; (5) an increase in imported energy price affects the economy by increasing the energy production, allocating more factors to produce energy, and reducing consumption and export of food.

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Appendix A

Closed Economy Model

The present value Hamiltonian problem defined in (2.1-2.11) can be shown as;

$$H = e^{-rt}u(y_t^d, f_t^d) + \varphi_t(F^y(k_t^y, N_t^y, L_t^y, U_t^y) - y^d{}_t - \delta k_t) \qquad \text{(A2.I)}$$

Where φ_t is the co-state variable of the state variable

The Present value Largrangian is

$$\begin{aligned} L = {} & e^{-rt}u(y_t^d, f_t^d) + \varphi_t(F^y(k_t^y, N_t^y, L_t^y, U_t^y) - y_t^d - k_t) \\ & -\mu_f[f_t^d - F^f(k_t^f, N_t^f, C_t^f, U_t^f)] \\ & -\mu_c[C_t^f + C_t^e - F^c(k_t^c, N_t^c, L_t^c, U_t^c)] \\ & -\mu_e[E_t^c - F^e(k_t^e, N_t^e, C_t^e, U_t^e)] \\ & +\eta_k[k_t - k_t^y - k_t^f - k_t^c - k_t^e] \\ & +\eta_N[\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e] \\ & +\eta_L[\overline{L} - L_t^y - L_t^c] \\ & +\eta_U[E_t^c - U_t^y - U_t^f - U_t^c - U_t^e] \end{aligned} \qquad \text{(A2.II)}$$

where; $\mu_f, \mu_c, \mu_e, \eta_k, \eta_N, \eta_L$, and η_U are the Largrangian multipliers for food production, raw cassava production, energy production, capital supply, labor supply, land supply, and energy supply, respectively.

To develop the current value necessary condition, the costate variable and Largrangian multipliers are defined as follow:

For costate variable; $\lambda_t = e^{rt}\varphi_t$ and $\dot{\lambda}_t = re^{rt}\varphi_t + e^{rt}\dot{\varphi}_t$ where λ_t is the current value of costate variable. The current value Largrangian multipliers are defined as

$\phi_k = e^{rt}\eta_k$, $\phi_N = e^{rt}\eta_N$, $\phi_L = e^{rt}\eta_L$, $\phi_U = e^{rt}\eta_U$, $\nu_C = e^{rt}\mu_C$, $\nu_f = e^{rt}\mu_f$, and $\nu_e = e^{rt}\mu_e$.

The current value necessary conditions for an interior solution of the maximum principle problem in equation (A2.II) are equations (A2.1)-(A2.28) as follow:

$$\frac{\partial u_t^*(y_t^d, f_t^d)}{\partial y_t^d} - \lambda_t^* = 0 \qquad \text{(A2.1)}$$

$$\frac{\partial u_t^*(y_t^d, f_t^d)}{\partial f_t^d} - \nu_f^* = 0 \qquad \text{(A2.2)}$$

$$\dot{\lambda}_t = (r+\delta)\lambda_t^* - \phi_k^* \qquad \text{(A2.3)}$$

$$\dot{k}_t = F^{y*}(.) - y_t^{d*} - \delta k_t^* \qquad \text{(A2.4)}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial C_t^f} - \nu_C^* = 0 \qquad \text{(A2.5)}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial C_t^e} - \nu_C^* = 0 \qquad \text{(A2.6)}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial k_t^y} - \phi_k^* = 0 \qquad \text{(A2.7)}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial k_t^f} - \phi_k^* = 0 \qquad \text{(A2.8)}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial k_t^c} - \phi_k^* = 0 \qquad \text{(A2.9)}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial k_t^e} - \phi_k^* = 0 \qquad \text{(A2.10)}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial N_t^y} - \phi_N^* = 0 \tag{A2.11}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial N_t^f} - \phi_N^* = 0 \tag{A2.12}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial N_t^c} - \phi_N^* = 0 \tag{A2.13}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial N_t^e} - \phi_N^* = 0 \tag{A2.14}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial L_t^y} - \phi_L^* = 0 \tag{A2.15}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial L_t^c} - \phi_L^* = 0 \tag{A2.16}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial U_t^y} - \phi_U^* = 0 \tag{A2.17}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial U_t^f} - \phi_U^* = 0 \tag{A2.18}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial U_t^c} - \phi_U^* = 0 \tag{A2.19}$$

$$\nu_e^* \frac{\partial F^{*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial U_t^e} - \phi_U^* = 0 \tag{A2.20}$$

$$\begin{gathered} \nu_f^*(f_t^{d*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)) = 0 \\ f_t^{d*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f) \le 0, \nu_f^* \ge 0 \end{gathered} \tag{A2.21}$$

$$\begin{gathered} \nu_c^*(C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)) = 0 \\ C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c) \le 0, \nu_c^* \ge 0 \end{gathered} \tag{A2.22}$$

$$\nu_e^{\ *}(E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)) = 0$$
$$E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e) \le 0, \nu_e^{\ *} \ge 0 \qquad \text{(A2.23)}$$

$$\overline{L} - L_t^{y*} - L_t^{c*} = 0 \qquad \text{(A2.24)}$$

$$k_t^{\ *} - k_t^{y*} - k_t^{f*} - k_t^{c*} - k_t^{e*} = 0 \qquad \text{(A2.25)}$$

$$\overline{N} - N_t^{y*} - N_t^{f*} - N_t^{c*} - N_t^{e*} = 0 \qquad \text{(A2.26)}$$

$$E_t^{c*} - U_t^{y*} - U_t^{f*} - U_t^{c*} - U_t^{e*} = 0 \qquad \text{(A2.27)}$$

$$-\nu_e^{\ *} + \phi_U^{\ *} = 0 \qquad \text{(A2.28)}$$

Appendix B

Open Economy Model

The present value Hamiltonian problem defined in (2.12-2.23) can be shown as:

$$H = e^{-rt}u(y_t^d, f_t^d) + \varphi_t(F^y(k_t^y, N_t^y, L_t^y, U_t^y) - y^d{}_t - y_t^{ex} - \delta k_t) \qquad \text{(B2.I)}$$

Where φ_t is the co-state variable of the state variable

The Present value Largrangian is;

$$\begin{aligned}
L &= e^{-rt}u(y_t^d, f_t^d) + \varphi_t(F^y(k_t^y, N_t^y, L_t^y, U_t^y) - y_t^d - y_t^{ex} - \delta k_t) \\
&-\mu_f[f_t^d + f_t^{ex} - F^f(k_t^f, N_t^f, C_t^f, U_t^f)] \\
&-\mu_c[C_t^f + C_t^e - F^c(k_t^c, N_t^c, L_t^c, U_t^c)] \\
&-\mu_e[E_t^c - F^e(k_t^e, N_t^e, C_t^e, U_t^e)] \\
&+\eta_k[k_t - k_t^y - k_t^f - k_t^c - k_t^e] \qquad \text{(B2.II)} \\
&+\eta_N[\overline{N} - N_t^y - N_t^f - N_t^c - N_t^e] \\
&+\eta_L[\overline{L} - L_t^y - L_t^c] \\
&+\eta_U[U_t + E_t^c - U_t^y - U_t^f - U_t^c - U_t^e] \\
&+\eta_T(p^f f_t^{ex} + p^y y_t^{ex} - p^u U_t)
\end{aligned}$$

where; $\mu_f, \mu_c, \mu_e, \eta_k, \eta_N, \eta_L, \eta_U$, and η_T are the Largrangian multipliers for food production, raw cassava production, energy production, capital supply, labor supply, land supply, energy supply, and trade balance, respectively.

To develop the current value necessary condition, the costate variable and Largrangian multipliers are defined as follow:

For costate variable; $\lambda_t = e^{rt}\varphi_t$ and $\dot{\lambda}_t = re^{rt}\varphi_t + e^{rt}\dot{\varphi}_t$ where λ_t is the current value of costate variable. The current value Largrangian multipliers are defined as;

$\phi_k = e^{rt}\eta_k$, $\phi_N = e^{rt}\eta_N$, $\phi_L = e^{rt}\eta_L$, $\phi_U = e^{rt}\eta_U$, $\phi_T = e^{rt}\eta_T$,$\nu_C = e^{rt}\mu_C$, $\nu_f = e^{rt}\mu_f$, and

$\nu_e = e^{rt}\mu_e$.

The current value necessary conditions for an internal solution of the maximum principle problem in equation (B2.II) are equations (B2.1)-(B2.32) as follow:

$$\frac{\partial u_t^*(y_t^d, f_t^d)}{\partial y_t^d} - \lambda_t^* = 0 \qquad \text{(B2.1)}$$

$$\frac{\partial u_t^*(y_t^d, f_t^d)}{\partial f_t^d} - \nu_f^* = 0 \qquad \text{(B2.2)}$$

$$\dot{\lambda}_t = (r+\delta)\lambda_t^* - \phi_k^* \qquad \text{(B2.3)}$$

$$\dot{k}_t = F^{y*}(.) - y_t^{d*} - y_t^{ex*} - \delta k_t^* \qquad \text{(B2.4)}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial C_t^f} - \nu_C^* = 0 \qquad \text{(B2.5)}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial C_t^e} - \nu_C^* = 0 \qquad \text{(B2.6)}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial k_t^y} - \phi_k^* = 0 \qquad \text{(B2.7)}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial k_t^f} - \phi_k^* = 0 \qquad \text{(B2.8)}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial k_t^c} - \phi_k^* = 0 \qquad \text{(B2.9)}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial k_t^e} - \phi_k^* = 0 \qquad \text{(B2.10)}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial N_t^y} - \phi_N^* = 0 \qquad \text{(B2.11)}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial N_t^f} - \phi_N^* = 0 \qquad \text{(B2.12)}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial N_t^c} - \phi_N^* = 0 \qquad \text{(B2.13)}$$

$$\nu_e^* \frac{\partial F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial N_t^e} - \phi_N^* = 0 \qquad \text{(B2.14)}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial L_t^y} - \phi_L^* = 0 \qquad \text{(B2.15)}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial L_t^c} - \phi_L^* = 0 \qquad \text{(B2.16)}$$

$$\lambda_t^* \frac{\partial F^{y*}(k_t^y, N_t^y, L_t^y, U_t^y)}{\partial U_t^y} - \phi_U^* = 0 \qquad \text{(B2.17)}$$

$$\nu_f^* \frac{\partial F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)}{\partial U_t^f} - \phi_U^* = 0 \qquad \text{(B2.18)}$$

$$\nu_C^* \frac{\partial F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)}{\partial U_t^c} - \phi_U^* = 0 \qquad \text{(B2.19)}$$

$$\nu_e^* \frac{\partial F^{*}(k_t^e, N_t^e, C_t^e, U_t^e)}{\partial U_t^e} - \phi_U^* = 0 \qquad \text{(B2.20)}$$

$$\begin{aligned} &\nu_f^*(f_t^{d*} + f_t^{ex*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f)) = 0 \\ &f_t^{d*} + f_t^{ex*} - F^{f*}(k_t^f, N_t^f, C_t^f, U_t^f) \le 0, \nu_f^* \ge 0 \end{aligned} \qquad \text{(B2.21)}$$

$$\begin{aligned} &\nu_c^*(C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c)) = 0 \\ &C_t^{f*} + C_t^{e*} - F^{c*}(k_t^c, N_t^c, L_t^c, U_t^c) \le 0, \nu_c^* \ge 0 \end{aligned} \qquad \text{(B2.22)}$$

$$\nu_e^{\ *}(E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e)) = 0$$
$$E_t^{c*} - F^{e*}(k_t^e, N_t^e, C_t^e, U_t^e) \leq 0, \nu_e^{\ *} \geq 0 \tag{B2.23}$$

$$\overline{L} - L_t^{y*} - L_t^{c*} = 0 \tag{B2.24}$$

$$k_t^{\ *} - k_t^{y*} - k_t^{f*} - k_t^{c*} - k_t^{e*} = 0 \tag{B2.25}$$

$$\overline{N} - N_t^{y*} - N_t^{f*} - N_t^{c*} - N_t^{e*} = 0 \tag{B2.26}$$

$$U_t^{\ *} + E_t^{c*} - U_t^{y*} - U_t^{f*} - U_t^{c*} - U_t^{e*} = 0 \tag{B2.27}$$

$$-\nu_e^{\ *} + \phi_U^{\ *} = 0 \tag{B2.28}$$

$$\lambda_t^{\ *} = p^y \phi_t^{\ *} \tag{B2.29}$$

$$\nu_f^{\ *} = p^f \phi_t^{\ *} \tag{B2.30}$$

$$\phi_U^{\ *} = p^u \phi_t^{\ *} \tag{B2.31}$$

$$p^f f_t^{ex*} + p^y y_t^{ex*} = p^u U_t^{\ *} \tag{B2.32}$$

ESSAY 3: ETHANOL EXPANSION AND AGRICULTURE IMPACTS

Introduction

An increase in ethanol production in Thailand has resulted from an alternative fuels plan designed by and heavily promoted by the Thai government since 2003. To enhance energy-security, the government has been implementing the alternative energy policies focused on increasing production and utilization of bio-fuels (e.g., ethanol and bio-diesel). The Renewable Energy Development Plan (REDP) 2008 requires the production and consumption of ethanol to rise from 1.4 million liters/day in 2009 to a target of 3.0 million liters/day by 2011 and to a target of 9.0 million liters/day by 2023. A tax incentive that has allowed gasohol to be sold at a cheaper price than premium gasoline has driven a large increase in ethanol demand in relatively few years. The rapid increase in ethanol demand has affected the production of feedstock crops, the most important of which are sugar cane and cassava.

Cassava, the field crop with the best cost advantage in processing as feedstock for ethanol production, has the greatest potential to expand in cultivation area, yield and productivity. Since 2005, total cassava production has increased due to high prices associated with increasing demand for ethanol. The increase in cassava production has increased the demand for land used for cassava, crowding out land for production of other agricultural products.

Allocating land to cassava production to meet government energy target for the next 15 years implies that the amount of land available for production of other crops, like maize or sugar cane, will fall, or new land must be drawn into agricultural production.

This will change the relative quantities produced and the relative prices of all affected crops. Thus, expansion of the ethanol industry could change the price of other food crops and livestock, affect farmer income, and affect the structure of the agriculture sector. As more than half of all Thai citizens are involved in agricultural production, the effects of ethanol expansion will be wide-spread. The purpose of this study is to estimate and forecast the impacts of ethanol expansion on the agricultural sector in Thailand. The study attempts to predict impacts on land used in cassava, maize, and sugar cane production, as well as the equilibrium levels of price and production for these three crops.

Literature Review

Effects of Ethanol Production in Agricultural Land Use

Studies on ethanol production's impact on land use and crop production have appeared with increasing frequency in the recent literature. In the United States, where corn is the primary feedstock for ethanol production, Westcott (2007) found that higher corn prices lead not only to increases in corn acreage, but also an adjustment in crop rotations between corn and soybean. Chakravorty, Magné, and Moreaux (2008) used a dynamic model of land allocation among crops used to produce food or clean energy. They found that land was allocated to produce more energy crops as the price of energy sources increases. When agricultural land is scare, farmland tends to be converted to be production of energy crops. When land is abundant, production of energy crops can expand even more rapidly.

Susanto, Rosson, and Hudson (2009) analyzed the effect of ethanol production on crop acreage using regression analysis. They analyzed the effect on corn, cotton, wheat and soybean acreage as a function of relative prices and a dummy variable measuring the government energy policy. Acreage response is relatively inelastic and an increase in corn price of 52% results in an increase in corn acreage of 41.83%. The some increase in corn price leads to an increase in soybean acreage of 0.59%, as well as decreases in cotton acreage of 20.43% and wheat acreage 6.44%. The demand for domestically produced corn is expected to rise by 11.5% annually for the period 2007-2013, while corn exports are expected to remain constant. Given the acreage response, the authors expect U.S. corn production to satisfy both domestic and export demands.

Effects of Ethanol Production on Agricultural Prices

Other studies have examined the impact of an increase in energy crop prices on ethanol production, competing crops and food prices. Baker, Hayes, and Babcock (2008) concluded that an increase in one crop price raises the equilibrium price of all crops. For example, corn and soybean, compete in land use, therefore the soybean price must increase if ethanol production causes a higher price of corn. Koo and Taylor (2008) analyzed the U.S. and world corn industries using a simulation model. They applied a global multi-commodity partial econometric model to world corn industries. The model has equilibrium conditions for the corn and soybean markets, which are solved simultaneously. The study found that an increase in the price of corn affects structural change in the corn industry. Higher forecasted prices of corn from $3.78 per bushel in 2008 to $ 4.40 in 2012 (under the ethanol production goal of 7 billion gallons per year) lead to an increase in corn production from 12.5 billion bushels in 2008 to 13.9 billion bushels in 2012. Corn exports and corn used as livestock feed would decrease because of higher ethanol production. The prices of corn, soybeans, wheat, high fructose corn syrup, and many agricultural inputs would also increase due to higher corn prices, simulated by ethanol production.

Fortenbery and Hwanil (2008) also studied the effect of ethanol production on U.S. national corn price, using a system of supply and demand to study short run corn prices. The system was composed of a price equation, a supply equation, a feed demand equation, an export demand equation, and a demand equation which includes industrial uses, ethanol uses. The system of equations was estimated simultaneously by 3SLS. They found that 1% increase in ethanol production lead to 0.16% increase in corn price.

Most of the studies of ethanol production and agricultural impacts done in the past had shown that increased ethanol production led to higher demand and prices of energy crops. An increase of energy crops used for ethanol production also raises the land used for these crops, while some of land is shifted from other crops. For this essay, the effects of ethanol production on prices, quantities, acreages of energy crop and related crops are studied using a partial equilibrium model that allows for changes in the market equilibrium for all related crops.

Theoretical Framework

The study uses regression analysis and time series econometrics to estimate the impact of ethanol production to the agricultural sector in Thailand. The models will be used to estimate and project the production of cassava; as well as competing crops, production of livestock, prices of cassava, farmer income and food prices. The model is developed to study a partial equilibrium for cassava and maize. It composes of cassava supply and demand, maize supply and demand, and harvested areas of cassava, maize, and sugar cane. The equilibrium condition is solved for equilibrium cassava prices and maize prices for present and future. The following describes the structure of the model.

A model of Cassava Supply and Demand

Cassava supply. Normally, the supply function can be expressed in the relationship between supply and factor affecting supply such as own price, price of related products, price of input, technology, expectation and government policy. In our simulation models, the supply functions for crops are determined by crop prices and average last period yield. The working assumption is that farmers do not know the prices before growing crops, and therefore base supply decisions on the expected price by using last year's price. Cassava supply is assumed as a function of last period prices of cassava, maize and sugar cane (which are the competing crops), and average last period yield.

$$Cassava_t = f(P_{t-1}^C, P_{t-1}^M, P_{t-1}^S, Y_{t-1}^C) \qquad (3.1)$$

where the notation and variables used in all equations are defined in Table 3.1.

Cassava demand. Demand functions show the relationship between quantity demanded and the factors that affect demand such as own price, price of related product, income, preference and expectation of price or income. Most of demands for agriculture crops are the derived demands which occur as a result of demands for other purpose. For example, the production of potato starch leads to a derived demand for potato.

Table 3.1

Variables in the Model

Variable	Definition
$Cassava_t$	Supply of cassava at time t
$Starch_t$	Cassava demand for starch at time t
$CFeed_t$	Cassava demand for feed at time t
Oth_demand_t	Cassava demand for other purposes at time t
E_t	Cassava demand for ethanol production at time t
Y_{t-1}^{C}	Average yield of cassava at time t-1
P_t^{C}	Cassava price at time t
P_{t-1}^{C}	Cassava price at time t-1
P_{t-1}^{M}	Maize price at time t-1
P_{t-1}^{S}	Sugar cane price at time t-1
Dc	Dummy variable of government policy on ethanol expansion after 2006
T	Time trend technology
$P_t^{C\_index}$	Index price of cassava product at time t
P_t^{Starch}	World price of cassava starch at time t
P_t^{feed}	Average price of feed in market at time t
P_t^{gas}	Average price of gasoline at time t
$Maize_t$	Supply of maize at time t
$Maize\_demand_t$	Demand of maize at time t
Y_{t-1}^{M}	Average yield of maize at time t-1
P_t^{M}	Maize price at time t
$P_t^{M\_index}$	Index price of maize product at time t
P_t^{ex}	Maize price for export at time t
$A^{C}{}_{t}$	Harvested area of cassava at time t
$A^{M}{}_{t}$	Harvested area of maize at time t
$A^{S}{}_{t}$	Harvested area of maize at time t
$Land_t$	Total land available for cassava, maize and sugar cane at time t

Currently in Thailand, Cassava is mainly used for three purposes; for livestock feed, starch production, and ethanol production. In the study, we focus on cassava demand for ethanol production, thus we determine cassava demand in two components which are cassava demand for ethanol and cassava demand for other purposes (starch and feed use). Cassava demand for ethanol is the derived demand associated with ethanol production.

Cassava demand for other purposes. Cassava demand for other purposes is computed from the summation between demand for starch and demand for feed use. Cassava demand for starch is a function of the price of cassava and the world price of cassava starch.

$$Starch_t = f(P_t^C, P_t^{Starch}) \tag{3.2}$$

Cassava demand for feed use is specified as a function of the price of raw cassava and the price of feed.

$$CFeed_t = f(P_t^C, P_t^{feed}) \tag{3.3}$$

To model the combined demand for cassava for "other purposes", we use an index of the starch price and feed price. The index price of cassava product ($P_t^{C\_index}$) is computed from weighted average prices of starch and feed.

Where; $P_t^{C\_index} = W_t^{Starch} \cdot P_t^{Starch} + W_t^{CFeed} \cdot P_t^{feed}$ and

$$W_t^{Starch} = \frac{Starch_t}{Starch_t + CFeed_t}, \quad W_t^{CFeed} = \frac{CFeed_t}{Starch_t + CFeed_t}$$

Thus, our demand needed is specified as in (3.4)

$$Oth\_demand_t = f(P_t^C, P_t^{C\_index}) \tag{3.4}$$

Cassava demand for ethanol production. The cassava demand for ethanol production is the derived demand for gasohol. It is assumed as the function of price of raw cassava, price of gasoline and dummy variable of government policy (3.5).

$$E_t = f(P_t^C, P_t^{gas}, Dc) \qquad (3.5)$$

Equilibrium condition for price of cassava. The equilibrium condition for cassava means that supply equals demand:

$$Cassava_t = Oth\_demand_t + E_t \qquad (3.6)$$

A Model of Maize Supply and Demand

Along with sugar cane, maize is a crop that competes for land with cassava. The largest maize production region is in the north and northeast parts of Thailand. Maize is primarily used for consumption by animals. After government promoted crop diversification from the National Economics and Social Plan in 1960s, maize became an important export crop as well as an import source of domestically produced livestock feed.

Maize Supply. The maize supply function is assumed to be function of the last period prices of three major crops (maize, cassava and sugar cane), and last period yield of maize (3.7).

$$Maize_t = f(P_{t-1}^M, P_{t-1}^C, P_{t-1}^S, Y_{t-1}^M) \qquad (3.7)$$

Maize demand. The two major uses of maize are for feed use in livestock industries and for export. In recent years, the domestic demand for maize in Thailand has increased due to an expanding of livestock industry, while export demand has fallen.

More than 80 % of total maize production is used domestically for feed use. Maize demand for feed use is set as a function of the price of maize and the price of feed (3.8).

$$MFeed_t = f(P_t^M, P_t^{feed}) \tag{3.8}$$

Maize exports are delivered mostly to neighbor countries such as Malaysia, Vietnam, Indonesia, and Philippines. The demand function of maize for export is set as a function of price of maize and export price in equation (3.9).

$$Export_t = f(P_t^M, P_t^{ex}) \tag{3.9}$$

In this essay, we will combine the demands for maize for feed use and for export into a single demand, as the summation of demand for feed use and for export. It can be specified as a function of maize price and maize index price which is derived from weighted average product prices of maize in equation (3.10).

$$Maize\_demand_t = f(P_t^M, P_t^{M\_index}) \tag{3.10}$$

Where; $P_t^{M\_index} = W_t^{Feed} \cdot P_t^{feed} + W_t^{\mathrm{ex}} \cdot P_t^{\mathrm{ex}}$ and

$$W_t^{MFeed} = \frac{MFeed_t}{MFeed_t + Export_t}, \quad W_t^{Export} = \frac{Export_t}{MFeed_t + Export_t}$$

Equilibrium condition for price of maize. The equilibrium condition for maize requires the supply of maize to be equal to maize demand:

$$Maize_t = Maize\_demand_t \tag{3.11}$$

Sugar Cane Supply and Demand

Sugar cane production in Thailand is regulated under the Sugar Act of 1984. The government estimates cane production, domestic demand, and export demand, and allocates the supply to three quotas, A, B and C. Quota A, or domestic demand, is allocated to registered mills at the beginning of the season and a fixed price is set for domestic sales. . Quota B is held by The Thai Cane and Sugar Corporation, a government entity that sells to international brokers and local millers for export. Quota C is the surplus for export by private firms. The production of sugar cane requires reaching target of Quota A and B first, and the remainder goes to Quota C. The fixed domestic price is set on the basis of negotiations between the government, growers, and mills. Growers receive 70 percent of revenue from domestic and export sales while the mills receive 30 percent.

The sugar cane industry has been highly regulated since 1984, with the price and the supply of sugar cane depending upon a government plan. Therefore, the price of sugar cane is considered as exogenous variable for this study.

Harvested Area Equations for Cassava, Maize and Sugar Cane

In this section, the harvested area equations are developed to analyze the impacts of ethanol expansion on agriculture land use in the partial equilibrium model. Agricultural statistics indicate that cassava, maize and sugar cane are the most important field crops in Thailand. The total harvested area of these tree major field crops is about 75% of total land use for field crops. In addition, maize and cassava compete for land in the northern and central part of Thailand while sugar cane and cassava compete for land in the northeastern part of Thailand. The Thai government's plan to expand ethanol production from cassava has resulted in an increase in the production and price of cassava. From 2006-2009, it can be seen that land use for cassava has been increasing while there has some decrease in land use for maize and sugar cane (Table 3.2).

Table 3.2

Thailand Cassava, Maize and Sugar Cane Harvested Area and Price

	Cassava		Maize		Sugarcane	
Year	Harvested area (Rais)	Price (Baht/tons)	Harvested area (Rais)	Price (Baht/tons)	Harvested area (Rais)	Price (Baht/tons)
2004	6,608,363	800	7,031,993	4,589	6,944,786	368
2005	6,161,928	1,330	6,704,473	4,778	6,470,169	520
2006	6,692,537	1,290	6,222,590	5,453	5,889,975	688
2007	7,338,809	1,180	6,187,449	6,892	6,163,874	683
2008	7,397,098	1,930	6,517,662	7,010	6,432,885	577
2009	8,292,146	1,190	6,794,744	5,140	5,827,908	700

Source: Office of Agricultural Economics, 2009

To construct harvested area equations, we assumes (1) Only maize and sugar cane are associated with changes in cassava land use, and (2) Total available land for three major field crops is fixed (this second assumption is later relaxed). The harvested area equation can be expressed in terms of last year's harvested area, its price, competitive crop prices and a dummy variable capturing the government's ethanol expansion program since 2006. The harvested area equations for cassava, maize, sugar cane and the restricted on total land use are given below:

$$A^C{}_t = f(A^C{}_{t-1}, P^C_{t-1}, P^M_{t-1}, P^S_{t-1}, Dc) \qquad (3.12)$$

$$A^M{}_t = f(A^M{}_{t-1}, P^M_{t-1}, P^C_{t-1}, P^S_{t-1}, Dc) \qquad (3.13)$$

$$A^S{}_t = f(A^S{}_{t-1}, P^S_{t-1}, P^C_{t-1}, P^M_{t-1}, Dc) \qquad (3.14)$$

$$Land_t = A^C{}_t + A^M{}_t + A^S{}_t \tag{3.15}$$

Partial Equilibrium Econometric Model
for the Cassava, Maize and Sugar Cane

In the partial equilibrium model, the economy is assumed to have three major field crops (cassava, maize, and sugar cane) that are the only field crops which have interactions among one another: the production of these three crops has no impact on other sectors of the economy. Government policy on these three crops is assumed constant throughout the period of analysis.

Focusing on equilibrium prices of cassava and maize and harvested area equations, the model will be solved simultaneously for (1) Equilibrium prices and quantities of cassava and maize and (2) The optimum harvested areas for cassava, maize and sugar cane.

The following equations (3.1)-(3.16) present the systems of equations of partial equilibrium econometric model for cassava, maize, and sugar cane:

$$Cassava_t = f(P^C_{t-1}, P^M_{t-1}, P^S_{t-1}, Y^C_{t-1}) \tag{3.1}$$

$$Oth\_demand_t = f(P^C_t, P^{C\_index}_t) \tag{3.4}$$

$$E_t = f(P^C_t, P^{gas}_t, Dc) \tag{3.5}$$

$$Cassava_t = Oth\_demand_t + E_t \tag{3.6}$$

Supply, demands and equilibrium condition for cassava

$$Maize_t = f(P^M_{t-1}, P^C_{t-1}, P^S_{t-1}, Y^M_{t-1}) \tag{3.7}$$

$$Maize\_demand_t = f(P^M_t, P^{M\_index}_t) \tag{3.10}$$

$$Maize_t = Maize\_demand_t \tag{3.11}$$

Supply, demand and equilibrium condition for maize

$$A^{C}{}_{t} = f(A^{C}{}_{t-1}, P^{C}_{t-1}, P^{M}_{t-1}, P^{S}_{t-1}, Dc) \quad (3.12)$$

$$A^{M}{}_{t} = f(A^{M}{}_{t-1}, P^{M}_{t-1}, P^{C}_{t-1}, P^{S}_{t-1}, Dc) \quad (3.13)$$

$$A^{S}{}_{t} = f(A^{S}{}_{t-1}, P^{S}_{t-1}, P^{C}_{t-1}, P^{M}_{t-1}, Dc) \quad (3.14)$$

$$Land_{t} = A^{C}{}_{t} + A^{M}{}_{t} + A^{S}{}_{t} \quad (3.15)$$

Harvested area equations for cassava, maize and sugar cane and the restricted on total land use

Step of Estimation

Coefficients estimation. In the first step, the system of equations (3.1)-(3.15) that govern cassava and maize markets is estimated simultaneously. The systems of demand and supply of cassava and maize satisfy both rank and order conditions with each system over identified. Thus, we can estimate the systems of in equations (3.1)-(3.6) and in equations (3.7)-(3.8) by using two stage least squares (2SLS).

The equations for harvest area do not have endogenous variables related issues but when the models include the same prices then the disturbance terms are correlated across equations (Greene, 2003). The harvest area equations estimated by seemingly unrelated regressions (SUR) method. By the method of 2SLS and SUR, the parameters of the econometric model can be estimated if we assume particular functional forms. The regression functions can be written as

$$Cassava_{t} = \alpha_{11} + \gamma_{11}P^{C}_{t-1} + \eta_{11}P^{M}_{t-1} + \mu_{11}P^{S}_{t-1} + \upsilon_{11}Y^{C}_{t-1} + \varepsilon_{11} \quad (3.16)$$

$$Oth\_demand_{t} = \alpha_{12} + \gamma_{12}P^{C}_{t} + \phi_{12}P^{C\_index}_{t} + \varepsilon_{12} \quad (3.17)$$

$$E_{t} = \alpha_{13} + \gamma_{13}P^{C}_{t} + \phi_{13}P^{gas}_{t} + \rho_{13}Dc + \varepsilon_{13} \quad (3.18)$$

$$Cassava_{t} - Oth\_demand_{t} - E_{t} = 0 \quad (3.19)$$

$$Maize_t = \alpha_{21} + \gamma_{21} P_{t-1}^C + \eta_{21} P_{t-1}^M + \mu_{21} P_{t-1}^S + \upsilon_{21} Y_{t-1}^M + \varepsilon_{21} \tag{3.20}$$

$$Maize\_demand_t = \alpha_{22} + \eta_{22} P_t^M + \phi_{22} P_t^{M\_index} + \varepsilon_{22} \tag{3.21}$$

$$Maize_t = Maize\_demand_t \tag{3.22}$$

$$Land_t - Am_t - As_t = \alpha_{31} + \beta_{31} Ac_{t-1} + \gamma_{31} P_{t-1}^C + \eta_{31} P_{t-1}^M + \mu_{31} P_{t-1}^S + \rho_{31} Dc + \varepsilon_{31} \tag{3.23}$$

$$Land_t - Ac_t - As_t = \alpha_{41} + \beta_{41} Am_{t-1} + \gamma_{41} P_{t-1}^C + \eta_{41} P_{t-1}^M + \mu_{41} P_{t-1}^S + \rho_{41} Dc + \varepsilon_{41} \tag{3.24}$$

$$Land_t - Ac_t - Am_t = \alpha_{51} + \beta_{51} As_{t-1} + \gamma_{51} P_{t-1}^C - \eta_{51} P_{t-1}^M + \mu_{51} P_{t-1}^S + \rho_{51} Dc + \varepsilon_{51} \tag{3.25}$$

Parameterize partial equilibrium econometric model. The system of equations (3.16)-(3.25) can be solved simultaneously for equilibrium prices of cassava and maize, supply and demand of cassava and maize, and harvested area for three major field crops. The system of equations (3.16)-(3.25) can be written in the matrix form as $A \cdot x = b$, where all exogenous variables Y_{t-1}^C, Y_{t-1}^M, $P_t^{C\_index}$, P_t^{gas}, $P_t^{M\_index}$, and P_{t-1}^S are moved to the b vector and all endogenous variables are in the x vector.

$$\begin{pmatrix}
1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & -\beta_{11} & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & -\gamma_{12} & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & -\gamma_{13} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & -\beta_{21} & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & -\eta_{22} & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0
\end{pmatrix} \bullet \begin{pmatrix}
Cassava_t \\ E_t \\ Oth_demand_t \\ Maize_t \\ Maize_demand_t \\ P_t^C \\ P_t^M \\ Ac_t \\ Am_t \\ As_t
\end{pmatrix} =$$

$$\begin{pmatrix} 0 \\ \alpha_{11} + \gamma_{11} P_{t-1}^{C} + \eta_{11} P_{t-1}^{M} + \mu_{11} P_{t-1}^{S} + \upsilon_{11} Y_{t-1}^{C} + \varepsilon_{11} \\ \alpha_{12} + \phi_{12} P_{t}^{C\_index} + \varepsilon_{12} \\ \alpha_{13} + \phi_{13} P_{t}^{gas} + \rho_{13} Dc + \varepsilon_{13} \\ \alpha_{21} + \gamma_{21} P_{t-1}^{C} + \eta_{21} P_{t-1}^{M} + \mu_{21} P_{t-1}^{S} + \upsilon_{21} Y_{t-1}^{M} + \varepsilon_{21} \\ \alpha_{22} + \phi_{22} P_{t}^{M\_index} + \varepsilon_{22} \\ 0 \\ -Land_{t} + \alpha_{31} + \beta_{31} Ac_{t-1} + \gamma_{31} P_{t-1}^{C} + \eta_{31} P_{t-1}^{M} + \mu_{31} P_{t-1}^{S} + \rho_{31} Dc + \varepsilon_{31} \\ -Land_{t} + \alpha_{41} + \beta_{41} Am_{t-1} + \gamma_{41} P_{t-1}^{C} + \eta_{41} P_{t-1}^{M} + \mu_{41} P_{t-1}^{S} + \rho_{41} Dc + \varepsilon_{41} \\ -Land_{t} + \alpha_{51} + \beta_{51} As_{t-1} + \gamma_{51} P_{t-1}^{C} - \eta_{51} P_{t-1}^{M} + \mu_{51} P_{t-1}^{S} + \rho_{51} Dc + \varepsilon_{51} \end{pmatrix} \tag{3.26}$$

Data

The simulation is based on Thailand's yearly national production and prices data base for cassava, maize, sugar cane, livestock and ethanol. For cassava supply, maize supply, and harvested area equations, the data includes harvested area, production and farm price of cassava, maize and sugar cane, obtained from the office of Agricultural Economics for 1989-2009 (Table A.1-A.3). Data set for price of starch, average market price of feed, and the quantity of cassava use as a feed stock for starch are obtained from Office of Industry Economics. The data for average price of gasoline and total ethanol production is obtained from Bureau of Petroleum and Petrochemical Policy. The data for cassava use as feed stock for ethanol production is derived from total ethanol production from cassava and is obtained from Office of Energy Policy and Planning. While data are scare for all the modeling, they are particularly scare for the cassava model. Thailand has started collecting data only in last 10 years; the data set is limited to the time period 2000-2009. The model assumes cassava demand for ethanol is equal to zero until 2005 after which Thailand began to blend ethanol with gasoline. The data set for the cassava model is shown in Table A.5 in the appendix.

For the maize model, the data set includes the price of maize for export, maize use for feed and maize use for export. The data for maize export quantity and price are obtained from office of Agricultural Economics. The data for quantity of maize use for feed is assumed to equal to the rest from maize export. The data set is shown in Table A.6 in Appendix A.

Results

The estimation results are presented in five parts. The first part reports results from the empirical systems demand and supply system, as well as the harvested area equations. The second part is the forecasting results for exogenous variables by using ARMA model. Part three shows the calibration results for partial equilibrium econometric model, where the calibration uses values obtained from first and second parts. The calibration is calculated using data in year 2007 to get the results for 2008 and using data in year 2008 to get the results for 2009. The fourth portion of the analysis is the projected values for all relevant variables in the model to measure the impacts of ethanol expansion on agriculture sector. The model is applied in different scenarios by changing government policy situations. Each scenario assumption is based on renewable energy development plan (REDP). The last part is the description of the calibration and scenario analysis results and implications for the agriculture sector.

Coefficient Estimation

The coefficient estimation results using 2SLS and SUR are presented in Table 3.3 for the cassava equilibrium, Table 3.4 for the maize equilibrium and Table 3.5 for the harvested area equations of cassava, maize, and sugar cane. In Table 3.3, all coefficients have the expected signs except the price of sugar cane in last period (P_{t-1}^{S}). The last period cassava price and cassava yield coefficients for supply equation are statistically significant at above 0.05 significant level; the t-statistics are given in parentheses. The supply equation was tested for multicollinearity problem. We select the Variance Inflation Factor (VIF) method to test if multicollinearity is a problem among the independent. All VIF statistics are less than 5, suggesting that these variables are not collinear.

For demand equations, the constant term in the "demand for other purposes" equation, the government dummy variables (Dc), and price of cassava (P_t^C) in the "cassava demand for ethanol" equation are not statistically significant. In addition, the derived demand for ethanol model exhibits a high R-square and low statistical significance in the explanatory variables. Thus, the "derived demand for ethanol" equation is tested for multicollinearity. The results show that the VIF for P_t^{gas} and Dc are less than the critical value of 5, and they do not indicate multicollinearity.

All estimated equations were examined for serial correlation through the Durbin-Watson statistics. The DW statistics indicate no serial correlation in "derived demand for other purposes" equation and inconclusive for cassava supply and derived demand for ethanol equations. Thus, we use the Q statistic to test these two equations. The Q statistic indicates no serial correlation of the cassava supply equation, but the “derived demand for ethanol” equation exhibits the serial correlation problem at 0.05 significance levels. Due to the very small degrees of freedom (only 10 observations) we are unable to correct for this problem.

The system of equations for supply and demand for maize is presented in Table 3.4. All signs of the estimated coefficient are unexpected with the exception of the lagged price of sugar cane in supply equation (P^S_{t-1}). All coefficients were insignificant. In the supply equation, it exhibits the low value of R-square with high standard error of regression. The demand equation for maize has statistically insignificant in all coefficients at above 0.05 significant levels except the constant term. The Q statistics suggest there are no serial correlation problems in the supply and demand system. In addition, the VIF statistics for maize supply and demand equations of high correlation coefficients are less than 5. We can conclude that there are no multicollinearity problems in maize system of equations.

Turning now to the harvested area model, the SUR results are presented in Table 3.5. The estimated coefficients for cassava harvested area equation (Ac_t) have the expected sign except lagged price of sugar cane (P^S_{t-1}) which is insignificant. The lagged values of cassava harvested area (Ac_{t-1}), the price of cassava (P^C_{t-1}), and the price of maize (P^M_{t-1}) are statistically significant. The cassava harvested area equation shows the high value of R-square with low standard error of regression.

Table 3.3

2SLS System Coefficient Estimation of Cassava Supply and Demand Equations

Variables	Cassava supply	Endogenous variables Derived Demand for other purposes	Derived demand for ethanol
$Constant$	-406,125 (-0.087)	-9,611,210 (-1.094)	-369,319.6 (-2.614)**
P_{t-1}^{C}	10,358.48 (4.083)***		
P_{t-1}^{M}	-1,260.63 (-0.922)		
P_{t-1}^{S}	15,349.90 (2.393)		
Y_{t-1}^{C}	3,058,532 (1.221)		
P_{t}^{C}		-10,577.78 (-1.094)*	-64.80 (-0.524)
$P_{t}^{C\_index}$		4415.43 (3.137)***	
P_{t}^{gas}			24.29 (2.770)**
Dc			127,229 (1.009)
Sample	10	10	10
R-squared	0.946	0.650	0.926
S.E. of regression	1,385,678	2,823,666	87,188

*** = 1 % significant level, ** = 5 % significant level, * = 10 % significant level

Table 3.4

2SLS System Coefficient Estimation of Maize Supply and Demand Equations

Variables	Endogenous variables	
	Maize supply	Maize demand
$Constant$	-4,894,638 (-0.505)	4,655,372 (7.163)***
P_{t-1}^{M}	-79.45 (-0.182)	
P_{t-1}^{C}	159.10 (0.325)	
P_{t-1}^{S}	-172.38 (-0.095)	
Y_{t-1}^{M}	-560,012 (-0.095)	
P_{t}^{M}		-46.17 (-0.289)
$P_{t}^{M\_index}$		-19.21 (-0.142)
Sample	10	10
R-squared	-0.074	0.246
S.E. of regression	301,125.6	213,127

*** = 1 % significant level, ** = 5 % significant level, * = 10 % significant level

Relative to the cassava area model, the model of harvested area of maize (Am_t) has lower R-square and higher value of standard error of regression. All of estimated coefficients in maize harvested area equations have the expected signs, but the constant term and lagged harvested area of maize are statistically significant at above 0.1 level of significance.

Table 3.5

SUR System Coefficient Estimation of Harvested Area Equation for Cassava, Maize, and Sugar Cane

Variables	Endogenous variables Land in cassava (Ac_t)	 Land in maize (Am_t)	 Land in sugar cane (As_t)
$Constant$	-651,297 (-0.683)	4,415,354 (2.914)***	776,924 (0.733)
Ac_{t-1}	0.947 (14.316)***		
Am_{t-1}		0.535 (4.321)***	
As_{t-1}			0.570 (3.340)***
P^C_{t-1}	1,410.582 (5.045)***	-645.827 (-1.426)	250.611 (0.557)
P^M_{t-1}	-214.787 (-2.265)*	197.492 (1.187)	-29.323 (-0.168)
P^S_{t-1}	1041.798 (0.997)	-2,616.564 (-1.611)	3,989.172 (2.340)*
Dc	175,759.4 (0.584)	-68,412.5 (-0.155)	-900,922 (-2.060)
Sample	20	20	20
R-squared	0.941	0.778	0.605
S.E. of regression	296,006	491,349	479,731

*** = 1 % significant level, ** = 5 % significant level, * = 10 % significant level

The signs of coefficients in harvested area of sugar cane equation (As_t) are expected except last time period price of cassava (P^C_{t-1}). The estimated equation exhibits the low value of R-square and high value of standard error of regression with only two coefficients that are statistically significant at above 0.1 significant level; (As_{t-1}) and (P_{t-1}^{S}).

Exogenous variable forecasting

The forecasting results for exogenous prices are present in Table 3.6. There are four estimated equations. The prices series of Y_{t-1}^{C}, Y_{t-1}^{M}, P_t^{S}, $P_t^{C\_index}$, P_t^{gas}, and $P_t^{M\_index}$ present a trend in their series thus the model is specified with trends stationary form (T) in ARMA model.

$$Y_t = c_1 + d_1 t + a_1 Y_{t-1} + \varepsilon_t + b_1 \varepsilon_{t-1} \qquad (3.27)$$

Where; d_1 is trend stationary coefficient, a_1 is the coefficient for AR (1) process and b_1 is the coefficient for MA (1) process. The ARMA model is used to forecast future value of the Y_t sequence (Ender, 2004). In the ARMA model, the selection criterion chosen for this study is AIC (Akaike Information Criterion). The value of AIC represents the goodness of fit; the value approaches $-\infty$ the better the fit. The models in this study are compared in the value of AIC in ARMA (p, q) process and p and q are selected to make the lowest AIC.

Applying the equation (3.27) to exogenous variables, average yield of cassava variable (Y_{t-1}^{C}) is modeled by AR (1) process with stationary trend to achieve the lowest AIC (Table 3.6). The average yield of maize is best fitted with ARMA (1, 1) process with trend stationary. The price of sugar cane (P_t^{S}) is best modeled as MA (1) process with stationary trend to achieve the lowest AIC relative to other processes. The model for sugar cane prices has a low R-square but statistically significant at 0.01 significant level.

The forecasted equation for index price of cassava products (starch and livestock feed), ($P_t^{C\_index}$) is estimated in MA (1) process with stationary trend to achieve the lowest AIC as well. All of coefficients are statistically significant at above 0.01 significant levels. The F statistic is above 0.01 significant levels, implying an overall fit. The price of gasoline forecast model (P_t^{gas}) exhibits an AR (1) process with stationary trend to have to lowest AIC value. The AR (1) coefficient is the only statistically significant variable in the model, yet. The model has the high value of R-square and F-statistic, suggesting a good fit. The final forecast model is the index price for maize product (food and export), ($P_t^{M\_index}$), is estimated in MA (1) process to has the low AIC value. All of coefficients are statistically significant at above 0.01 significant levels. The R-square is above 0.9 and F-statistics significantly suggest a good overall fit.

The forecasted values of variables in Table 3.6 is shown and compared to the observed data in Appendix B.

Parameterize the partial equilibrium model and calibration evaluation

We use the coefficient values from the previous modeling. The estimated coefficients from systems models effort to use in the partial equilibrium model and substituted into matrix form (3.26) as the parameter values, while the exogenous values from forecast models are substituted as forecasted values of exogenous variables. After substituting all relevant values into equation (3.26), we solve the system to find the equilibrium values for quantities, prices and harvested area for cassava, maize and sugar cane ($Cassava_t, E_t, Oth\_demand_t, Maize_t, P_t^C, P_t^M, Ac_t, Am_t, As_t$).

Table 3.6

Coefficient Estimation of ARMA Model for Forecasted Prices

Coefficient	Forecasted prices					
	Y_{t-1}^{C}	Y_{t-1}^{M}	P_t^{S}	$P_t^{C\_index}$	P_t^{gas}	$P_t^{M\_index}$
$Constant$	1.683 (9.987)***	0.479 (9.644)***	318.25 (7.236)***	-2,297.114 (4.211)***	-110,491.3 (-0.388)	3,197.95 (6.325)***
T	0.087 (7.038)***	0.0084 (3.292)***	14.351 (4.12)***	447.05 (14.447)***	5,584.67 (0.813)	377.505 (13.161)***
$AR(1)$	0.351 (1.823)*	0.775 (6.046)***			0.935 (9.023)***	
$MA(1)$		-0.997 (-8.377)***	0.398 (1.663)	-0.997 (-4.803)***		-0.997 (-5.084)***
Sample	20	20	20	10	18	10
R-squared	0.880	0.962	0.634	0.929	0.978	0.920
AIC	-0.339	-5.158	-0.8893	-2.599	-2.2976	-3.6614
F-Statistic	(62.61)***	(136.10)***	(15.58)***	(46.23)***	(338.19)***	(40.62)***

*** = 1 % significant level, ** = 5 % significant level, * = 10 % significant level

Model parameterization using 2SLS estimators. The partial equilibrium model is calibrated by using the values of coefficient estimators from Table 3.3, 3.4 and 3.5 as values for parameters in matrix form equations (3.26). The model is calibrated by 2007 data to get the results for 2008 and by 2008 data to get the results for 2009. The results of calibration are shown in Table 3.7. This table presents the observed data and the calibration results for 2008 and 2009. The calibration evaluation is computed by using absolute percentage different between observed data and calibration results in percentage. The average absolute a percentage difference between observed data and predicted values for 2008 is 8.9% and 2009 is 5.5%.

Table 3.7

Evaluation of Predictive Ability, 2SLS Estimators

	Observed data		Predicted results		Absolute percentage difference $(\frac{\lvert Observed - Modeled \rvert}{Observed}\%)$	
	2008	2009	2008	2009	2008	2009
Cassava supply	25,155,797	30,088,024	22,696,036	30,804,245	9.78%	2.38%
Cassava demand for Other purposes	24,569,997	29,433,478	22,208,433	30,196,702	9.61%	2.59%
Cassava demand for ethanol	585,800	654,545	487,603	607,542	16.76%	7.18%
Equilibrium price of Cassava (Baht)	1,930	1,190	1,683	1,114	12.80%	6.36%
Maize supply and demand	4,249,354	4,448,524	4,069,932	4,172,630	4.22%	6.20%
Equilibrium price of Maize (Baht)	7,010	5,140	8,208	5,827	17.09%	13.36%
Harvested area of Cassava	7,397,098	8,292,146	7,249,562	8,077,292	1.99%	2.59%
Harvested area of maize	6,432,885	5,827,908	6,682,372	6,085,303	3.88%	4.42%
Harvested area of Sugar cane	6,517,662	6,794,744	5,856,649	6,286,788	10.14%	7.48%
Total land use	20,347,645	20,914,798	19,788,583	20,449,383	2.75%	2.23%
Average absolute percentage difference					**8.90%**	**5.48%**

The model was then used to predict equilibrium prices, quantities, and land area for next 10 years (2010-2019) by using 2009 data set. The results show large oscillations in quantities and prices (Appendix B, Graph B.2). We suspect this is due to the lack of data for estimating 2SLS estimators for systems of cassava demand and supply (10 years).

Model parameterization using OLS estimators. Thus, we decide to keep data and degree of freedom for estimators into the estimation for systems of cassava and maize as much as we can do. The OLS estimators for system of cassava and maize are applied in calibration of the partial equilibrium model instead of the 2SLS estimators.

In this section, supply equations using OLS method have more ten years of data with imply greater degree of freedom than supply equations using 2SLS. The results of OLS estimators for system of cassava and maize are shown in Table 3.8 and 3.9, respectively. Parameter values estimated for cassava and maize are substituted into matrix form equations (3.26) following the procedure used previously.

In Table 3.8, all coefficients from OLS estimation have the expected signs except the lagged price of sugar cane. The constant, last period cassava price, and last period average yield of cassava variables in supply equation are statistically significant at above 0.05 significant level. We have 20 observations, which is twice the observation available in the 2SLS estimation for cassava supply. In addition, the estimated parameters in supply equation are quite different from the 2SLS model. For demand equations, the values of coefficient in OLS estimation are quite similar the 2SLS estimation.

Table 3.9 shows the OLS estimations for supply and demand equations for maize. All signs of the estimated coefficients are expected. The lagged prices of cassava, maize, sugar cane, and average last period yield are not statistically significant and are quite different from the 2SLS estimation. Again the supply equation has more observations than in the 2SLS estimation. The R-square for the supply and demand equations are slightly higher.

Table 3.8

OLS System Coefficient Estimation of Cassava Supply and Demand Equations

Variables	Cassava supply	Endogenous variables Derived demand for other purposes	Derived demand for ethanol
$Constant$	3,564,067 (0.885)	-8,362,799 (-0.992)	-370,498.6 (-2.629)**
P_{t-1}^{C}	7,184.12 (2.517)**		
P_{t-1}^{M}	-1,436.41 (-1.137)		
P_{t-1}^{S}	4,344.27 (0.485)		
Y_{t-1}^{C}	5,147,584 (2.058)**		
Dc			127,453.1 (1.011)
P_{t}^{C}		-9,451.64 (-1.877)*	-60.363 (-0.510)
$P_{t}^{C\_index}$		4,158.62 (3.158)***	
P_{t}^{gas}			24.06 (2.784)**
Sample	20	10	10
R-squared	0.65	0.653	0.926
S.E. of regression	2,477,680	2,813,627	87,178.33

*** = 1 % significant level, ** = 5 % significant level, * = 10 % significant level

Table 3.9

OLS System Coefficient Estimation of Maize Supply and Demand Equations

Variables	Endogenous variables	
	Maize supply	Maize demand
$Constant$	3,232,514 (5.154)***	4,251,885 (8.642)***
P_{t-1}^{M}	127.83 (0.896)	
P_{t-1}^{C}	-285.90 (-0.839)	
P_{t-1}^{S}	-261.71 (-0.228)	
Y_{t-1}^{M}	1,381,569 (0.836)	
P_{t}^{M}		-225.30 (-2.354)**
$P_{t}^{M\_index}$		118.66 (1.362)
Sample	20	10
R-squared	0.292	0.497
S.E. of regression	323,538	173,975

*** = 1 % significant level, ** = 5 % significant level, * = 10 % significant level

All models in Table 3.8 and 3.9 are tested for serial correlation through the Q statistic and for multicollinearity through the VIF statistic. In the cassava models, only cassava demand for ethanol exhibited a serial correlation problem at 0.05 significance levels. Due to the small sample size and limited degrees of freedom, we are unable to correct this problem.In the maize model, both supply and demand equations are tested for serial correlation problem with Q statistics. The results indicate no serial correlation for these two equations. All VIF statistics indicate no multicollinearity at 0.05 significance levels.

The model parameterization using the OLS estimators is evaluated in a manner identical to that use the previously. We use 2007 data to predict the results for 2008 and then do the same with the 2008 data to predict for 2009 values. The results are shown in Table 3.8. The average absolute percentage different between observe data and calibration in year 2008 is 10.99 % and in year 2009 is 6.29%.

The predictive error using the OLS parameters shows a larger percentage differences, especially in equilibrium prices of cassava and maize. The observed prices of both cassava and maize in 2009 were lower in 2008; the model predictions do not change as much as the observed data (and the price of maize moves up rather than down). The observe data for the cassava demand for ethanol shows large differences from the predictive model. The cassava demand increases significantly, while the predicted results do not capture this trend, after Thai government start promoting gasohol E10 and E20 in 2006.

In this study, we use the results of the OLS estimators to parameterize in the partial equilibrium model to analyze the impacts on quantities, prices, and harvested areas of cassava, maize, and sugar cane. Results using the 2SLS parameters show very large oscillations in prices and quantities of cassava, and maize. Appendix B shows the projected graph from the model using 2SLS estimators.

Table 3.10

Evaluation of Predictive Ability, OLS Estimators

	Observed data		Predicted results		Absolute percentage difference ($\frac{\lvert Observed - Modeled \rvert}{Observed}$ %)	
	2008	2009	2008	2009	2008	2009
Cassava supply	25,155,797	30,088,024	22,376,357	28,108,275	11.05%	6.58%
Cassava demand for Other purposes	24,569,997	29,433,478	21,891,470	27,516,795	10.90%	6.51%
Cassava demand for ethanol	585,800	654,545	484,886	591,481	17.23%	9.63%
Equilibrium price of Cassava (Baht)	1,930	1,190	1,744	1,345	9.65%	13.04%
Maize supply and demand	4,249,354	4,448,524	4,517,076	4,325,801	6.30%	2.76%
Equilibrium price of Maize (Baht)	7,010	5,140	4,484	5,532	36.04%	7.62%
Harvested area of Cassava	7,397,098	8,292,146	7,249,562	8,077,292	1.99%	2.59%
Harvested area of maize	6,432,885	5,827,908	6,682,372	6,085,303	3.88%	4.42%
Harvested area of Sugar cane	6,517,662	6,794,744	5,856,649	6,286,788	10.14%	7.48%
Total land use	20,347,645	20,914,798	19,788,583	20,449,383	2.75%	2.23%
Average absolute percentage difference					**10.99%**	**6.29%**

Projected Future Quantities, Prices, and Harvested Areas under Ethanol Targets

In this section, the model using OLS estimators is simulated for next 10 years (2010-2019) to describe the future values of all relevant variables in the model. The nine endogenous variables in the partial equilibrium model are the quantity of cassava ($Cassava_t$), the quantity of cassava for ethanol (E_t), the quantity of cassava for other purposes (Oth_demand_t), the price of cassava (P_t^C), the quantity of maize ($Maize_t$), the price of maize (P_t^M), the harvested areas of cassava (Ac_t), maize (Am_t), and sugar cane (As_t). The model is parameterized with three sources of data; (1) from OLS estimators for demand and supply of cassava and maize in Table 3.8 and Table 3.9, (2) from SUR estimators for harvested areas in Table 3.5, and (3) from the ARMA forecasting values for exogenous prices in Table 3.6.

The projected impacts on Thai agriculture are described by future values of the endogenous variables in the model. The model is simulated in four scenarios by differencing ethanol targets and production plans. The model is applied in four scenarios; (1) baseline scenario is the basic model using forecasts of exogenous prices to project future cassava demand for ethanol. In this scenario, cassava demand for ethanol is determined as an endogenous variable; (2) three alternative scenarios use equation (3.26) as a baseline scenario but treat cassava demand for ethanol (E_t) as an exogenous variable. Each scenario has different value for cassava demand for ethanol depending on different government targets. In all scenarios, the model assumes 0.5% per year increase in land used. This assumption bases on the average growth of agricultural land use from 2000 to 2009, which is about 0.5% per year.

Baseline scenario. In baseline scenario, the model determines future values of all nine endogenous variables defined in equation (3.26) for 2010 to 2019 using forecast values of exogenous prices (Table 3.11). Cassava supply and demand are seen to significantly increase over the next 10 years, cassava price trend to increase in next 10

Table 3.11

Forecasted Quantities and Prices of Cassava and Maize, and Harvested Areas

Unit: thousand tons

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Cassava supply	26,993	29,519	28,944	31,610	30,727	33,772	32,465	35,987	34,154	37,811
Cassava demand for other purposes	26,336	28,768	28,118	30,684	29,722	32,661	31,272	34,680	32,766	36,304
Cassava demand for ethanol	658	751	827	926	1,005	1,112	1,193	1,307	1,388	1,507
Equilibrium price of Cassava (Bahts)	1,667	1,606	1,872	1,797	2,095	1,981	2,325	2,161	2,560	2,382
Maize supply and demand	4,324	4,266	4,350	4,260	4,366	4,254	4,383	4,245	4,404	4,221
Equilibrium price of Maize (Bahts)	5,739	6,193	6,022	6,619	6,348	7,044	6,668	7,481	6,975	7,984
Harvested area of Cassava	8,443	8,899	9,301	9,836	10,254	10,839	11,265	11,891	12,312	12,975
Harvested area of maize	6,115	5,613	5,572	5,035	5,006	4,402	4,418	3,735	3,817	3,043
Harvested area of Sugar cane (thousand rais)	5,994	6,143	5,885	5,991	5,705	5,829	5,493	5,656	5,259	5,478

years with the cobweb price movement. The predicted values for maize shows a slightly decreasing quantity in the next 10 year while showing an increasing price.

The structure of land used for cassava, maize, and sugar cane in 2019 is significantly changed from the baseline year of 2009. The share of land used for cassava, maize, and sugar cane in 2009 is 39.65%, 32.49%, and 27.86%, respectively, whereas in 2019, the share of land used for cassava increases to 60.36%, maize decreases to 14.15%, whereas sugar cane is almost stable at 25.48% (computed from Table 3.11).

Alternative scenarios. In this section, the demand for ethanol is considered to be exogenous variable to represent the future government targets in different scenarios to get more accuracy and to analyze the effects on agriculture sector.

The model is applied to determine cassava demand for ethanol as exogenous variable. The model forecasts values of eight endogenous variables for 2010 to 2019.

Table 3.12

Scenario 1: Renewable Development Plan 2008 Target

Item	2009	2010	2011	2012-2016	2017-2023
	Medium run			Long run	
Ethanol Production Government Target (Million liters/day)	1.34	2.11	2.96	6.20	9.00
Ethanol from molasses (%)	70%	60%	50%	30%	20%
Ethanol from molasses (Ml/day)	0.938	1.26	1.48	1.86	1.80
molasses demand for ethanol (Million tons)	1.36	1.84	2.16	2.71	2.63
Ethanol from new alternative energy crop				10%	20%
Ethanol from cassava (%)	30%	40%	50%	60%	60%
Ethanol from cassava(Ml/day)	0.402	0.844	1.48	3.72	5.4
Cassava demand for ethanol (Million tons)	**0.86**	**1.81**	**3.18**	**7.99**	**11.61**

Source: Energy Planning and Policy Office, 2008

The three alternative scenarios:

Scenario 1, cassava demand for ethanol in next ten years is set to follow the Renewable Energy Development Plan (REDP) of the Thai government. The plan is shown in Table 3.12. The Thai government has set a long run ethanol production target of 9 million liters per day in 2017-2023. The ethanol produced from cassava is expected to reach 60% of total ethanol production with the remainder of ethanol produced from other sources (molasses and new alternative energy crops).The REDP defined the converting ratio between cassava and ethanol as 1 million tons of cassava can be produced ethanol 0.465 million liters/day. Thus, the 0.402 ml/day of ethanol production in 2009 requires about 0.86 million tons of cassava. The ethanol from cassava is expected to increase in the long run until it reaches the target of 5.4 ml/day in 2017-2023 which requires about 11.61 million tons of cassava.

Table 3.13

Scenario2: Renewable Development Plan 2008 with No Production from New Alternative Energy

Item	2009	2010	2011	2012-2016	2017-2023
	Medium run			Long run	
Ethanol Production Government Target (Million liters/day)	1.34	2.11	2.96	6.20	9.00
Ethanol from molasses (%)	70%	60%	50%	50%	40%
Ethanol from molasses (Ml/day)	0.938	1.26	1.48	3.10	3.6
molasses demand for ethanol (Million tons)	1.36	1.84	2.16	4.52	5.256
Ethanol from new alternative energy crop				0%	0%
Ethanol from cassava (%)	30%	40%	50%	50%	60%
Ethanol from cassava(Ml/day)	0.402	0.844	1.48	3.10	5.4
Cassava demand for ethanol (Million tons)	**0.86**	**1.81**	**3.18**	**6.66**	**11.61**

Scenario 2, the ethanol production on government target is the same as in scenario 1, but we assume no discovery of new alternative energy. Ethanol is only produced from two sources, molasses and cassava. Between 2012 and 2016, ethanol from molasses is set to account 50% of total ethanol production as same as ethanol from cassava. After 2016, ethanol from cassava is set to account 60% of total ethanol production (Table 3.13).

Scenario 3 assumes that the government target cannot be reached. There is no new alternative energy and the ethanol target is reduced. Between 2012 and 2016, the ethanol production target is set to reduce from 6.2 million liters/day to 4.0 million liters/day. Ethanol production from cassava is expected to account 60% of total ethanol production in 2012-2016 and 70% of total ethanol production in 2017-2023 (Table 3.14).

Table 3.14

Scenario 3: Renewable Development Plan 2008 with the Reduced Target

Item	2009	2010	2011	2012-2016	2017-2023
		Medium run		Long run	
Ethanol Production Government Target (Million liters/day)	1.34	2.11	2.96	4.00	6.00
Ethanol from molasses (%)	70%	60%	50%	40%	30%
Ethanol from molasses (Ml/day)	0.938	1.26	1.48	1.6	1.8
molasses demand for ethanol (Million tons)	1.36	1.84	2.16	2.33	2.628
Ethanol from new alternative energy crop				0%	0%
Ethanol from cassava (%)	30%	40%	50%	60%	70%
Ethanol from cassava(Ml/day)	0.402	0.844	1.48	2.4	4.2
Cassava demand for ethanol (Million tons)	**0.86**	**1.81**	**3.18**	**5.16**	**9.03**

The results for all three alternative scenarios are compared and shown in Tables 3.15, 3.16, and 3.17. In Table 3.15, the predicted in partial equilibrium model for quantity and price for cassava under scenarios 1, 2, and 3 are presented. It shows that scenario 2 requires highest quantity of cassava supply in next 10 years. Scenario 3 shows a lower cassava demand for ethanol for 2017-2019 than other two scenarios, resulted in a lower equilibrium price of cassava price. It can be seen that increasing ethanol production affects all scenarios by increasing cassava production and price in over the relevant time period. Moreover, cassava demands for other purposes increase in the same direction due to an increasing of forecast index price of cassava over the next 10 years.

Table 3.16 shows the results for maize production and price. Output under all scenarios show slightly decreasing quantities. The equilibrium price of maize for all scenarios increases from 2010 to 2019, with scenario 1 the greatest increase in 2018.

Table 3.15

Predicted Quantities and Prices of Cassava for Scenarios 1, 2, and 3

Unit: thousand tons, Price: bahts

Scenario	System of cassava	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Supply	28,108	27,562	29,817	30,533	35,454	32,323	37,731	33,724	40,179	37,741
	Demand for other purposes	26,768	25,752	26,637	22,543	27,464	24,333	29,741	25,734	28,569	26,131
	Demand for ethanol	1,340	1,810	3,180	7,990	7,990	7,990	7,990	7,990	11,610	11,610
	Equilibrium price	1,424	1,729	1,832	2,462	2,138	2,666	2,290	2,911	2,808	3,262
2	Supply	28,108	27,562	29,817	30,533	34,443	32,337	36,625	33,860	38,933	39,045
	Demand for other purposes	26,768	25,752	26,637	23,873	27,783	25,677	29,965	27,200	27,323	27,435
	Demand for ethanol	1,340	1,810	3,180	6,660	6,660	6,660	6,660	6,660	11,610	11,610
	Equilibrium price	1,424	1,729	1,832	2,321	2,104	2,523	2,266	2,756	2,939	3,124
3	Supply	28,108	27,562	29,817	30,533	33,302	32,353	35,378	34,013	37,529	38,554
	Demand for other purposes	26,768	25,752	26,637	25,373	28,142	27,193	30,218	28,853	28,499	29,524
	Demand for ethanol	1,340	1,810	3,180	5,160	5,160	5,160	5,160	5,160	9,030	9,030
	Equilibrium price	1,424	1,729	1,832	2,162	2,066	2,363	2,240	2,581	2,815	2,903

Table 3.16

Predicted Quantities and Prices of Maize for Scenarios 1, 2, and 3

Unit: thousand tons, Price: bahts

Scenario	System of maize	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Equilibrium output	4,326	4,301	4,262	4,288	4,126	4,344	4,103	4,381	4,079	4,313
	Equilibrium price	5,532	5,840	6,214	6,296	7,212	6,444	7,713	6,680	8,217	7,378
2	Equilibrium output	4,326	4,301	4,262	4,288	4,167	4,331	4,151	4,360	4,135	4,244
	Equilibrium price	5,532	5,840	6,214	6,296	7,033	6,503	7,500	6,771	7,969	7,686
3	Equilibrium output	4,326	4,301	4,262	4,288	4,212	4,316	4,205	4,337	4,198	4,243
	Equilibrium price	5,532	5,840	6,214	6,296	6,832	6,569	7,259	6,874	7,689	7,687

We conclude that an ethanol expansion affects maize by reducing its production and raising its price in next 10 years.

The forecasted areas of cassava, maize, and sugar cane production for all scenarios are shown in Table 3.17. All scenarios show increasing cassava harvested areas, decreasing maize harvested areas, and slightly decreased sugar cane harvested areas. The forecasted results imply that in next 10 years, land will be allocated more to produce cassava and that mostly comes from land for maize.

Agriculture Impacts

Based on the results in Table 3.13, 3.14, and 3.15, it can be explained that agricultural sector has two mainly impacts; direct impacts for cassava and indirect impacts for other crops.

Table 3.17

Predicted Harvested Area of Cassava, Maize, and Sugar Cane for Scenario 1, 2, and 3

Unit: thousand rais

Scenario	Harvested area	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Cassava	8,077	8,514	9,020	9,603	10,631	11,244	12,151	12,643	13,519	14,252
	Maize	6,085	6,023	5,531	5,261	4,278	4,381	3,307	3,607	2,423	2,485
	Sugar cane	6,287	6,014	6,103	5,895	5,953	5,341	5,612	4,926	5,340	4,651
2	Cassava	8,077	8,514	9,020	9,603	10,504	11,098	11,911	12,413	13,203	14,099
	Maize	6,085	6,023	5,531	5,261	4,440	4,438	3,553	3,697	2,730	2,423
	Sugar cane	6,287	6,014	6,103	5,895	5,918	5,431	5,607	5,066	5,350	4,866
3	Cassava	8,077	8,514	9,020	9,603	10,361	10,933	11,640	12,153	12,846	13,680
	Maize	6,085	6,023	5,531	5,261	4,623	4,502	3,829	3,798	3,075	2,668
	Sugar cane	6,287	6,014	6,103	5,895	5,878	5,531	5,602	5,224	5,361	5,040

Direct impacts for cassava. An ethanol expansion implies an increase in cassava production in next several years. The forecasting results show significantly higher in cassava price than its price in the present. The higher cassava price affects cassava use for other purpose such as for starch production and for feed use. The equation of cassava demand for other purposes shows that cassava use for food and for feed seems to reduce in future when cassava price increases.

They affects directly to food industry and livestock sector to higher cost of using cassava as feedstock. Moreover, an increased use of cassava for ethanol production and higher cassava price induce farmers to increase cassava acreage. This increase chiefly comes from shifting maize and sugar cane acreages.

Indirect impacts for other crops. An increase in cassava price encourage to an increase in cassava production while the production of other crops trend to decrease. The results indicate that maize and sugar cane which are the completing crops on sharing land use will decline on their planting and production. Some acreage from maize and sugar cane are shifted for planting cassava. With reduced in maize production, maize price tends to rise in future. It affects indirectly to livestock industry by using maize for feeding animals. Higher in maize price means an increase in cost of feeding livestock. Based on the forecasted sugar cane harvested area in Table 3.15, it indicates that harvested area for sugar cane in future almost has the same sharing ratio of land use comparing to present. Sugar cane has less effect from ethanol expansion than maize.

It can be noticed that an increase in ethanol production affects on agriculture sector on many aspects: the production of cassava, maize, and sugarcane, prices, land allocation, and livestock production. In the future, the ethanol expansion seems to have highly impact on agriculture sector than the present. The production of ethanol from energy crops requires large scale production from agriculture sector. The higher demand for energy crops drives their prices higher and also raises the prices of competing crops. This affects all stakeholders both farmers and consumers.

Conclusion

The study analyses the effects of an increasing in ethanol production to agriculture sector. The systems of demand and supply equations for cassava and maize are estimated by 2SLS. The system of harvested area equations for three major filed crops (cassava, maize, and sugar cane) is estimated by SUR. The study develops the partial equilibrium model to project the impacts of ethanol expansion on agriculture sector in Thailand for next ten years. The exogenous prices for the model are estimated by ARMA. The demand and supply of cassava and maize coefficients in the model are substituted by OLS estimators instead of 2SLS estimators because sample sizes are limited. The model is applied into four analyses: baseline which follows the partial equilibrium model, scenario 1 follows the government REDP target, scenario 2 follows the government REDP target but assumes no discovery of new potential energy crops, and scenario3 applies the reduced REDP target and assumes no new discovery of new energy crops.

The results indicate that increasing ethanol production in Thailand has a significant increase in cassava production and cassava price. It directly impacts on increasing in cassava acreage and declining in competing crop acreages. The agriculture sector is affected from higher cassava price by shifting land use from other crops to plant cassava. The prices of other crops will increase and the cost of feeding animal will higher. It implies that energy crop farmers will receive higher crop prices while livestock producers will take higher cost of feeding. In addition, an ethanol expansion seems to adjust the structure of agriculture sector at present from a leading maize producer and exporter to be a leading cassava producer for ethanol production. The government policy on ethanol production directly affects on agriculture sector for all field crops and livestock production. The results from all scenarios express the future change to agriculture sector. The government policy needs to concern all effects to all stakeholders and carefully applied to use in economy.

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Appendix A

Table A.1

Cassava Harvested Area, Production and Price

Year	Harvest area (Rai)	Production (tons)	Yield per Rai (kgs)	Farm price (Baht/kg)	Farm Value (M Baht)
1989	9,957,275	24,264,026	2,437	0.54	13,102.574
1990	9,297,125	20,700,511	2,227	0.63	13,248.327
1991	8,959,871	19,705,040	2,199	0.83	16,355.183
1992	9,065,866	20,355,723	2,245	0.77	15,673.907
1993	8,987,608	20,202,897	2,248	0.66	13,333.912
1994	8,641,845	19,091,347	2,209	0.58	11,072.981
1995	7,782,231	16,217,378	2,084	1.15	18,649.985
1996	7,675,710	17,387,780	2,265	1.00	17,387.780
1997	7,689,879	18,083,579	2,352	0.68	12,296.834
1998	6,527,382	15,590,556	2,388	1.25	19,488.195
1999	6,658,967	16,506,625	2,479	0.91	15,021.029
2000	7,068,388	19,064,284	2,697	0.63	12,010.499
2001	6,557,801	18,395,801	2,805	0.69	12,693.103
2002	6,176,376	16,868,309	2,731	1.05	17,711.724
2003	6,386,477	19,717,534	3,087	0.93	18,337.307
2004	6,608,363	21,440,487	3,244	0.80	17,152.390
2005	6,161,928	16,938,245	2,749	1.33	22,527.866
2006	6,692,537	22,584,402	3,375	1.29	29,133.879
2007	7,338,809	26,915,541	3,668	1.18	31,760.338
2008	7,397,098	25,155,797	3,401	1.93	48,550.688
2009	8,292,146	30,088,024	3,628	1.19	35,804.749

Source: Office of Agricultural Economics, 2009

Table A.2

Maize Harvested Area, Production and Price

Year	Harvest area (Rai)	Production (tons)	Yield per Rai (kgs)	Farm price (Baht/kg)	Farm Value (M Baht)
1989	10,686,537	4,392,579	411	2.93	12,867.511
1990	9,657,094	3,722,266	385	2.45	9,128.331
1991	8,741,323	3,792,652	434	2.77	10,507.687
1992	7,724,881	3,672,022	475	2.78	10,203.570
1993	7,610,466	3,328,228	437	2.82	9,400.697
1994	8,445,933	3,965,339	469	2.96	11,726.201
1995	7,896,251	4,154,518	526	4.06	16,877.127
1996	8,216,603	4,532,610	552	3.92	17,765.760
1997	7,487,846	3,831,647	512	4.40	16,866.993
1998	8,628,052	4,617,455	535	3.70	17,083.828
1999	7,541,292	4,286,440	568	4.31	18,464.898
2000	7,614,295	4,472,903	587	3.82	17,081.063
2001	7,529,354	4,496,960	597	3.95	17,757.788
2002	7,166,679	4,259,289	594	4.14	17,648.054
2003	6,895,443	4,248,989	616	4.43	18,819.398
2004	7,031,993	4,341,474	617	4.59	19,925.723
2005	6,704,473	4,093,634	611	4.78	19,561.532
2006	6,222,590	3,918,332	630	5.45	21,369.529
2007	6,187,449	3,890,218	629	6.89	26,813.486
2008	6,517,662	4,249,354	652	7.01	29,787.972
2009	6,794,744	4,448,524	655	5.14	22,865.413

Source: Office of Agricultural Economics, 2009

Table A.3

Sugar Cane Harvested Area, Production and Price

Year	Harvest area (Rai)	Production (tons)	Yield per Rai (kgs)	Farm price (Baht/kg)	Farm Value (M Baht)
1989	4,272,593	37,997,004	8,893	331	12,577.008
1990	4,288,880	33,618,125	7,838	389	13,077.451
1991	4,889,450	40,948,517	8,375	460	18,836.318
1992	5,727,242	47,953,605	8,373	335	16,064.458
1993	6,197,434	40,289,117	6,501	352	14,181.769
1994	4,997,116	37,822,874	7,569	462	17,474.168
1995	5,766,904	50,597,340	8,774	435	22,009.843
1996	6,156,274	57,973,530	9,417	385	22,319.809
1997	6,126,633	56,393,460	9,205	409	23,064.925
1998	5,664,052	43,464,950	7,674	506	21,993.265
1999	5,655,351	50,331,567	8,900	496	24,964.457
2000	5,583,459	54,052,125	9,681	445	24,053.196
2001	5,235,047	49,562,886	9,468	514	25,475.323
2002	6,162,620	60,012,977	9,738	435	26,105.645
2003	6,906,941	74,258,521	10,751	469	34,827.246
2004	6,944,786	64,995,741	9,359	368	23,918.433
2005	6,470,169	49,586,360	7,664	520	25,784.907
2006	5,889,975	47,658,097	8,091	688	32,788.771
2007	6,163,874	64,365,482	10,442	683	43,961.624
2008	6,432,885	73,501,611	11,426	577	42,410.430
2009	5,827,908	66,782,715	11,459	700	46,747.901

Source: Office of Agricultural Economics, 2009

Table A.4

Cassava Quantity for Starch, Ethanol and Feed Use and Product Prices

Year	Cassava for starch production tons	Cassava for ethanol production tons	Cassava for feed use tons	Price of starch baht/ton	Price of gasoline baht/M liters	Price of feed baht/ton
2000	2,449,071		16,615,213	5,924.36	15,640	8,105.18
2001	2,124,579		16,271,222	7,485.00	15,510	8,320.25
2002	2,336,005		14,532,304	8,086.00	15,280	8,699.74
2003	3,124,683		16,592,851	6,808.00	16,600	9,094.58
2004	3,113,400		18,327,087	8,266.90	19,060	9,863.29
2005	2,592,880		14,345,365	11,760.00	23,890	9,929.25
2006	3,443,331	245,454	18,895,617	8,587.00	27,550	9,658.50
2007	2,998,637	348,636	23,568,268	12,720.00	29,180	10,122.99
2008	2,780,949	585,800	21,789,048	13,490.00	35,640	12,395.90
2009	3,112,856	654,545	26,320,622	11,140.00	38,260	11,285.14

Source: Office of Agricultural Economics, Thai Tapioca Starch Association ,
Bureau of Petroleum and Petrochemical Policy, Office of Industry Economics, 2009

Table A.5

Maize Quantity for Feed Use and for Export, and Price of Maize for Export

Year	Price of maize for export	Maize for feed use	Maize for export
	baht/ton	tons	tons
1998	5,070.00	4,494,742.00	122,713.00
1999	4,070.00	4,218,060.00	68,380.00
2000	5,580.00	4,452,963.00	19,940.00
2001	4,520.00	4,006,110.00	490,850.00
2002	4,870.00	4,113,239.00	146,050.00
2003	5,080.00	4,059,569.00	189,420.00
2004	5,720.00	3,469,684.00	871,790.00
2005	5,733.33	4,034,974.00	58,660.00
2006	6,427.50	3,668,562.00	249,770.00
2007	8,070.00	3,657,216.00	233,002.00
2008	9,239.17	3,788,805.00	460,549.00
2009	7,341.67	3,670,112.00	778,412.00

Source: Office of Agricultural Economics, 2009

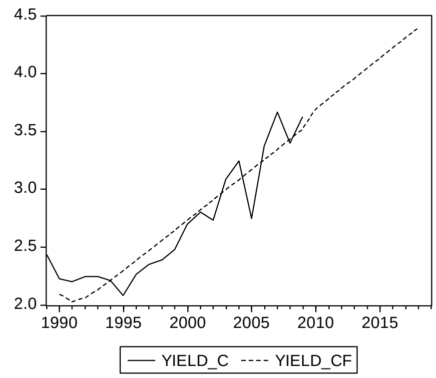
Appendix B

Table B.1

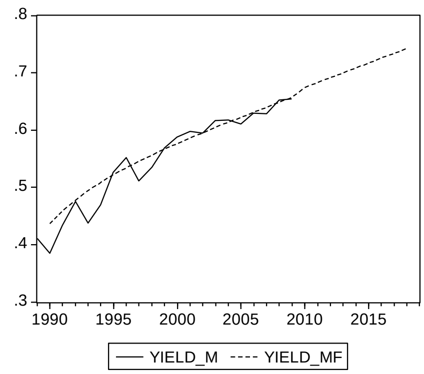
The Forecasted Exogenous Prices P_t^S , $P_t^{C\_index}$, P_t^{gas} , and $P_t^{M\_index}$ and Observed Data

year	Y_t^C		Y_t^M		P_t^S		$P_t^{C\_index}$		P_t^{gas}		$P_t^{M\_index}$	
	Observed data	Forecast value	Observed data	Forecast value	Observed data	Forecast value	Observed data	Forecast value	Observed data	Forecast value	Observed data	Forecast value
1989	2.437	-	0.411	-	331	333	-	2,744	-	-	-	3,576
1990	2.227	2.092	0.385	0.437	389	347	-	3,191	-	-	-	3,953
1991	2.199	2.028	0.434	0.459	460	361	-	3,638	10,060	-	-	4,331
1992	2.245	2.062	0.475	0.477	335	376	-	4,085	9,290	8,950	-	4,708
1993	2.248	2.131	0.437	0.494	352	390	-	4,532	9,090	8,272	-	5,086
1994	2.209	2.212	0.469	0.509	462	404	-	4,979	8,570	7,997	-	5,463
1995	2.084	2.297	0.526	0.522	435	419	-	5,427	9,050	8,101	-	5,841
1996	2.265	2.383	0.552	0.534	385	433	-	5,874	9,320	8,558	-	6,218
1997	2.352	2.470	0.512	0.546	409	447	-	6,321	10,480	9,346	-	6,596
1998	2.388	2.558	0.535	0.556	506	462	-	6,768	11,860	10,443	-	6,973
1999	2.479	2.645	0.568	0.566	496	476	-	7,215	11,980	11,830	-	7,351
2000	2.697	2.733	0.587	0.576	445	491	7,825	7,662	15,640	13,487	8,094	7,728
2001	2.805	2.820	0.597	0.586	514	505	8,224	8,109	15,510	15,398	7,905	8,106
2002	2.731	2.908	0.594	0.595	435	519	8,615	8,556	15,280	17,546	8,568	8,483
2003	3.087	2.995	0.616	0.604	469	534	8,732	9,003	16,600	19,915	8,916	8,861
2004	3.244	3.083	0.617	0.613	368	548	9,632	9,450	19,060	22,492	9,031	9,238
2005	2.749	3.170	0.611	0.622	520	562	10,210	9,897	23,890	25,262	9,869	9,616
2006	3.375	3.257	0.630	0.631	688	577	9,493	10,344	27,550	28,215	9,453	9,993
2007	3.668	3.345	0.629	0.639	683	591	10,416	10,791	29,180	31,337	10,000	10,371
2008	3.401	3.432	0.652	0.648	577	605	12,520	11,238	35,640	34,618	12,054	10,748
2009	3.628	3.520	0.655	0.657	700	620	11,270	11,685	38,260	38,047	10,595	11,126
2010	-	3.695	-	0.674	-	634	-	12,132	-	41,616	-	11,503
2011	-	3.782	-	0.682	-	648	-	12,579	-	45,314	-	11,881
2012	-	3.870	-	0.691	-	663	-	13,026	-	49,134	-	12,258
2013	-	3.957	-	0.699	-	677	-	13,473	-	53,068	-	12,636
2014	-	4.045	-	0.708	-	691	-	13,920	-	57,109	-	13,013
2015	-	4.132	-	0.716	-	706	-	14,368	-	61,249	-	13,391
2016	-	4.219	-	0.725	-	720	-	14,815	-	65,482	-	13,768
2017	-	4.307	-	0.733	-	734	-	15,262	-	69,802	-	14,146
2018	-	4.394	-	0.742	-	749	-	15,709	-	74,204	-	14,523
2019	-	-	-	-	-	763	-	16,156	-	78,682	-	14,901

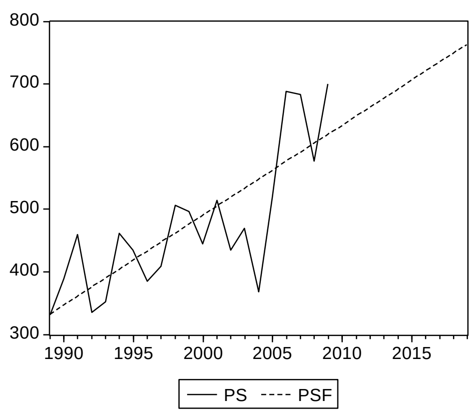
Graph B.1. The forecasted exogenous variables Y_t^C , Y_t^M , P_t^S , $P_t^{C\_index}$, P_t^{gas} , and $P_t^{M\_index}$ and observed data



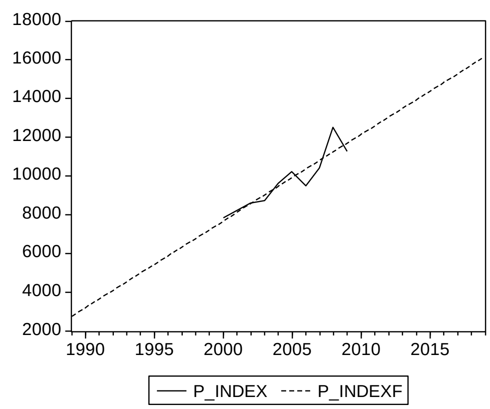
Picture 1: Y_t^C and observed data



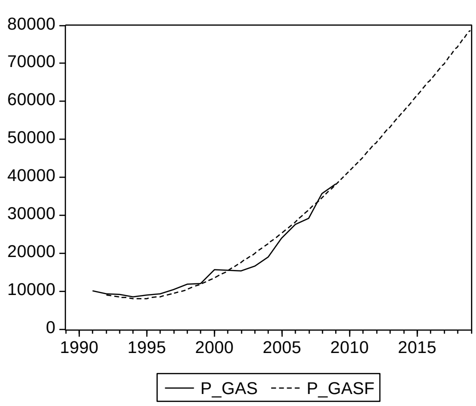
Picture 2: Y_t^M and observed data



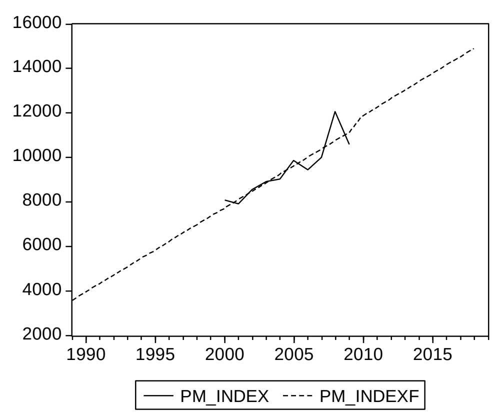
Picture 3: P_t^S and observed data



Picture 4: $P_t^{C\_index}$ and observed data

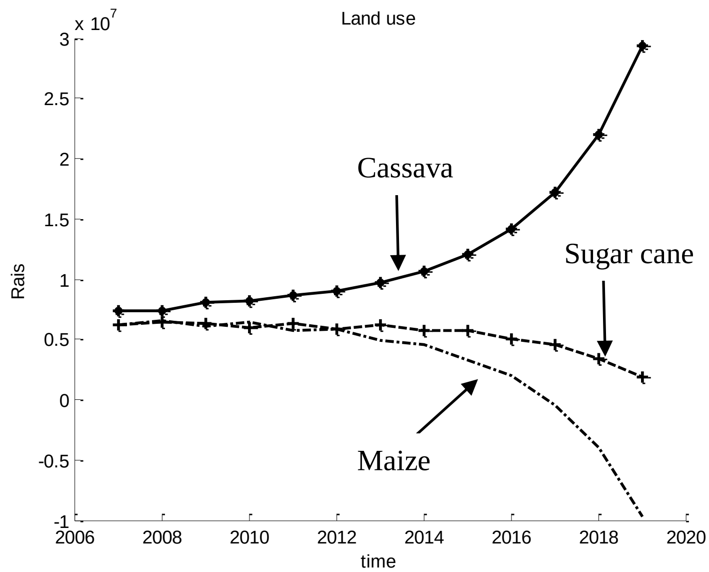


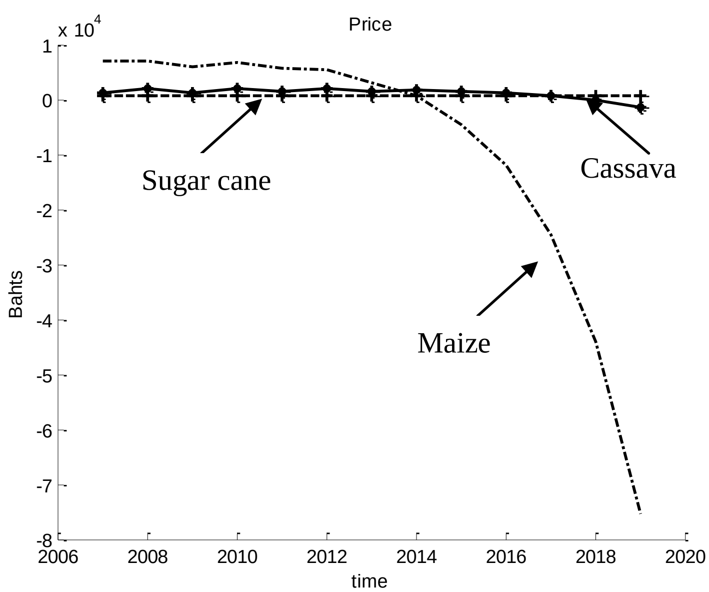
Picture 5: P_t^{gas} and observed data



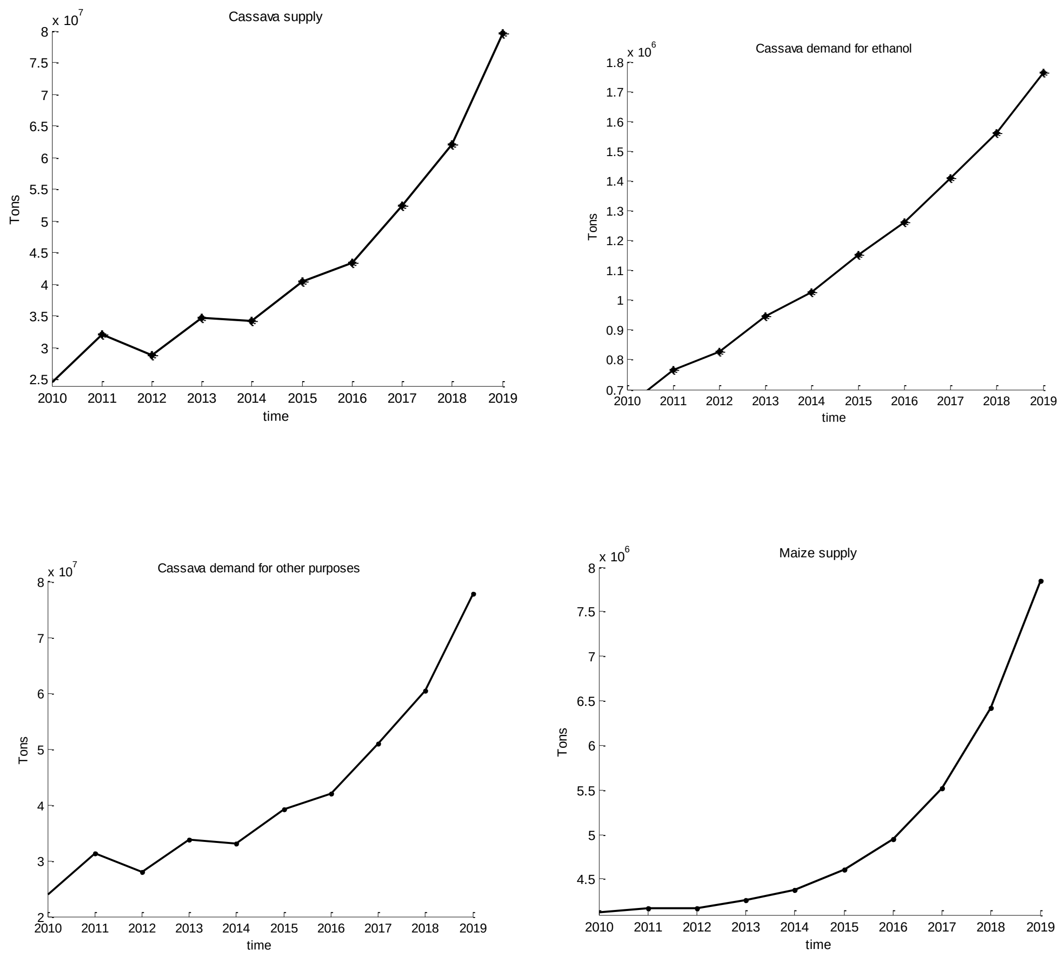
Picture 6: $P_t^{M\_index}$ and observed data

Graph B.2. The high divergence in partial equilibrium model using 2SLS parameters





Graph B.2. Continued



CONCLUSIONS

This dissertation studies a number of issues concerning the production of bio fuels from energy crops. We develop a dynamic general equilibrium model of an energy crop to plan a country's resources to achieve a sustainable development goal. The model is then analyzes to study the effect of international trade, and the effects of changes in labor supply, land supply, and imported energy prices on food and energy production, as well as social welfare. Futhermore, we study the impacts of an increase in ethanol production on agriculture sector. A partial equilibrium econometric model is developed to forecast the future impacts of government ethanol production targets on quantities, prices, and land uses of three major field crops (cassava, maize, and sugar cane) in Thailand.

In the first essay, a dynamic general equilibrium model is developed and calibrated using data from Thailand. The utility and production functions are specified using Cobb-Douglas functions. The stationary state solution gives the set of optimal consumption, production, and allocation of resources in economy. We also derive the approximation of optimal policy function and optimal time paths by using two methods: a linear approximation and the Runke-Kutta reverse shooting method. The results of the model provide information for decision makers to help them plan their economy to achieving sustainable development goals.

The second essay extends the dynamic general equilibrium model to both closed economy and open economy models. Under noth baseline models, we analyse the effect of changes in labor supply, land supply, and imported energy prices. The stationary state solutions from baseline models and scenario analysis suggest that international trade increases welfare and decreases energy price. An increase in labor supply results in a welfare increase and a decrease in the relative price of labor. An increase in land supply results in reduction of imported energy and higher welfare. And an increase in imported energy price affects to a welfare loss, higher bio energy production, and lower food production.

The third essay studies the effects of an increase in ethanol production on the agricultural sector. The results of the partial equilibrium model indicate that in next ten years Thailand will experience a significant increase in cassava production and cassava price. More land will be shifted to cassava production; land use willshift away from the production of maize and sugar cane. The price of maize will increase in future. It implies that casava and maize farmers will receive a higher prices while livestock producers will face a higher cost of feeding animals.

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