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Ex-ante Impact Assessment of GM Papaya Adoption in Thailand

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Despite the evidence of benefits from GM papaya's adoption in other countries, concerns over the loss of export markets and health and environmental risks have led to great uncertainty and indecision about policies to support biotechnology in Thailand. Since 2001, field trials have been banned and the use of transgenic plants for production, consumption, or commercialization has been prohibited. Field trials in government fields were reinstated in December 2007, but agricultural biotechnology policies remain unclear. This article estimates what the economic impact of the adoption of GM papaya would be if Thailand were to authorize the use of GM technology. We estimate that total economic surplus in the range of $650 million to $1.5 billion USD would be generated within the first 10 years of adoption. These benefits would accrue primarily to small-scale papaya farmers and would accrue even with the loss of export markets.

Key words: GM papaya, ex-ante assessment, Thailand.

Introduction

Thailand was among the first Asian countries to recognize the benefits of agricultural biotechnology. The National Center for Genetic Engineering and Biotechnology (BIOTEC) was established in 1983 to support the development and adoption of biotechnology. Since that time, BIOTEC—together with the Department of Agriculture (DOA) and several universities—has continued to conduct genetic engineering research. The Center for Agricultural Biotechnology (CAB) was established in 1999 through the collaboration of five academic institutions to enhance post-graduate study and to promote collaborative research in agricultural biotechnology. Although the 6th National Social and Economic Development Plan (1987-1991) emphasized biotechnology, it has not been consistently supported, and policy constraints have increased. These inconsistent policies have blocked the use of transgenics and caused the loss of millions of dollars of economic benefits.

The first transgenic crop to be field tested in Thailand was the Flavr Savr tomato in 1994; it was to be cultivated for seed production destined for export only. Field trials of Bt cotton began in 1996, but permission for the commercial release of Bt cotton still has not occurred. In response to public protest over Bt cotton field trials, the Thai government suspended all field trials of GM crops on April 3, 2001, until national biosafety regulation could be devised and implemented. Since then, research and development of agricultural biotechnology has been hindered. Biosafety regulation has yet to be completed, even though work on a biosafety guideline has been in process since June 1992. Despite the opposition of GM technology by activists, some scientists strongly believe that GM crops have great potential to solve energy and food security problems. As a result, the Thai government on December 25, 2007, reinstiuted permision for field trials of GM crops, but only in government fields.

In 1999, amendment of the 1964 Plant Quarantine Act strengthened the regulation to include all possible GM plant varieties. On March 17, 2000, 40 transgenic varieties (with exceptions for grains of GM corn and soybeans) were banned from importation. On October 14, 2003, an additional 49 transgenic varieties were listed as prohibited items for import except for processed products.

As of May 2009, no commercialization of GM crops is allowed in Thailand due to fear of losing export markets and environmental and health concerns. There is little public information available on the costs and benefits of GM technology to the Thai economy, and national policies and research and application plans are yet to be made. The economic evaluation of transgenic crops is essential to the development of appropriate future agricultural biotechnology policies. This article provides an ex-ante economic evaluation of the use of GM papaya in Thailand. Papaya is in the most advanced stage of development among GM crops. Implications from this study could be used to evaluate potential biotechnology policies in the future.

Table 1. Papaya area, production, average yield, and price, 1988-2007.

	Production area (ha)		Total production (ton)	Average yield (ton/ha)		
Year	Planted	Bearing		Planted	Harvested	Price (baht/kg)
1992	23,876	17,309	346,305	14.50	20.01	3.83
1993	24,447	18,615	363,579	14.87	19.53	3.92
1994	25,848	19,776	367,987	14.24	18.61	3.98
1995	24,525	18,492	342,772	13.98	18.54	4.38
1996	25,639	19,156	335,433	13.08	17.51	4.41
Average 92-96	*24,867*	*18,670*	*351,215*	*14.12*	*18.81*	*4.10*
1997	24,490	18,888	316,879	12.94	16.78	5.25
1998	27,647	19,030	367,861	13.31	19.33	5.43
1999	30,024	22,161	412,138	13.73	18.60	4.87
2000	24,953	20,228	366,828	14.70	18.14	5.11
2001	23,400	16,327	290,854	12.43	17.81	5.04
Average 97-01	*26,103*	*19,327*	*350,912*	*13.44*	*18.16*	*5.14*
2002	23,672	18,966	351,693	14.86	18.54	3.89
2003	22,511	17,436	309,003	13.73	17.72	4.96
2004	20,375	16,077	277,923	13.64	17.29	5.69
2005	8,820	5,534	30,961	3.51	5.59	5.89
2006	13,378	8,171	134,443	10.05	16.45	6.98
Average 02-06	*17,751*	*13,237*	*220,805*	*12.44*	*16.68*	*5.48*
2007	16,795	11,609	195,377	11.63	16.83	9.00
Growth rate 97-06	*-0.45*	*-0.57*	*-0.58*	*-0.22*	*-0.02*	*0.33*

Note. Data from Ministry of Agriculture and Cooperatives, Department of Agricultural Extension (2007).

Development of GM Papaya in Thailand

Papaya has traditionally been a staple crop in both the national diet and in the mixed cropping system of small farmers in Thailand. The most commonly grown varieties are Khakdam and Khaknuan. Thailand is currently a small producer of papaya. In 2006, Thailand produced less than 2% of the world's papaya, ranking as the world's 12th-largest producer (Food and Agricultural Organization of United Nations [FAO], 2007). The average yield from 2002-2006 was 11.16 tons/hectare, a decline from 14.13 tons/hectare average yield from 1992-1996 (Table 1); this was largely due to an increase in disease. More than 98% of total papaya production is consumed in the country; both green and ripe papayas are common in fresh and prepared dishes. Green papayas are consumed as a vegetable, and papaya salad or "Som Tum" is a very popular dish in everyday consumption, particularly in the Northeast area. Ripe papayas are consumed as fresh fruits, while a small share of production is processed and preserved. The majority of papaya exports are processed products rather than fresh produce. Seventy-four percent of total papaya export is in the form of canned, valued at about 84% of total papaya exports (The Customs Department of Thailand, 2006).

Papaya ring spot virus (PRSV) is a severe problem in papaya production, and there is no immediate means to control the spread of the virus nor the yield loss. Since PRSV was first discovered in Northeastern Thailand in 1975, it has spread throughout the country. Papaya area and production fell by more than one-half between 1997 and 2006. Based on interviews with members of the Thai papaya industry, insufficient supply of papaya could result in future imports from neighboring countries, though there have been no papaya imports so far. Angyurekul and Tugsinavisuth (2003) analyzed the papaya industry during the period of 1988-2001 and found that the infestation of PRSV was one of the most important production problems, and the lack of research and development of PRSV-resistant varieties poses a major threat to the industry.

Several attempts have been initiated to develop PRSV-resistant papaya. In 1987, a research team at the Horticultural Research Institute, Khon Kaen Agricultural Research Station of the DOA bred a tolerant variety by crossing "Florida tolerant" with "Khakdam." By 1994, three lines of PRSV-resistant hybrids—Thapra 1, Thapra 2, and Thapra 3—were developed, providing average yields of 66.4 tons/hectare. Until 2004, Thapra 2 (renamed "Khakdam Thapra") was the primary variety recommended by DOA and was distributed to 37 provinces in the Northeast and other regions. Khakdam Thapra is partially resistant to PRSV; however, it could still eventually become infected after a few years of production or if planted in an infested area (US Department of Agriculture [USDA], 2005). Currently, no papaya seeds are distributed to farmers by the Northeast Regional Office of Agriculture (NEROA) due to as-of-yet unsubstantiated accusations that the station allowed GM seeds to escape the confines of the station.

GM PRSV-resistant papaya was successfully developed through the collaboration between Thailand DOA and Cornell University in 1995. In 1997, two transformed varieties, Khakdam and Khaknuan, were transferred to the Thapra research station in the Khon Kaen province for further breeding and analysis in a confined greenhouse. Field trials began at the station in 1999 and continued until 2004. Selected third-generation lines from both transformed varieties showed 97-100% resistance to the virus (Davidson, 2006) and provided an average yield of 73.8 tons/hectare (USDA, 2005). On July 27, 2004, Greenpeace sealed off an experimental field of GM papaya at the Khon Kaen agricultural research station and demanded that the government immediately destroy all papaya trees, fruit, seedlings, and seeds to prevent further "contamination." They claimed that tests conducted by GeneScan Ltd. (Hong Kong) found the presence of GM papaya in farmers' fields despite the Plant Quarantine Act.

In addition to the research done by DOA, two other projects have been intiated to create GM PRSV-resistant papaya. The first was under the Papaya Biotechnology Network (PBN) of Southeast Asia, which was supported locally by BIOTEC at the Plant Genetic Engineering Unit (PGEU) at the Kasetsart University's Kamphangsan campus. The GM PRSV-resistant vareity was successfully developed in work dating to 1997. Plant materials from Queensland University in Australia twice were brought in for the purpose of conducting research to create resistance to PRSV and to extend the ripening period; the first time was in August 1998, and the second time was in May 2000. Field trials were ongoing at PGEU until 2004 when the moratorium on field testing of GM crops was put in place. The other research project was initiated in 1994 at the Institute of Molecular Biology and Genetics at Mahidol University.

Economic Evaluation of GM Papaya

Although several studies have evaluated the economic impacts of GM crops, only a few were of GM papaya, and few have applied to Thailand. Gonsalves, Lee, and Gonsalves (2004) conducted a farmer survey in June–September 1999 in the Puna area of Hawaii. They found that the adoption rate of the Rainbow PRSV-resistant variety was at 76% from May 1998 to September 1999. Sankula and Blumenthal (2004) estimated the benefit of PRSV-resistant papaya in Hawaii by comparing the annual data to the base year (1998) when it first became available. They found that the yield increase ranged from 16% to 77%, production value increased from $1.14-5.54 million from 1999 to 2003 with no change in production cost. Brookes and Barfoot (2008) summarized the benefits of GM crops in several countries. By reviewing the studies by Sankula (2006) and Sankula and Blumenthal (2004), they found that GM PRSV-resistant papaya could provide 16% to 50% yield improvement from 1999 to 2006 in the United States. There was no cost to farmers for acquiring the technology from 1999 to 2003, but in 2004, the cost increased to $42/hectare and then increased to $148/hectare from 2005 to 2006.

Paris, Carambas, McMeniman, and Lubulwa (2002) used the generalized unit cost reduction model to estimate the impact of Australian Centre for International Agricultural Research (ACIAR)-supported projects in the Philippines based on a preliminary evaluation by Bantilan (1992) that PRSV-resistant varieties could result in a 50% reduction in unit cost based on a 350% increase in yield. By assuming a maximum adoption rate of 100% and nine-year research lags, they found that PRSV-resistant hybrids could result in savings of AUD $3.46 million in the base case (50% cost reduction) and increase to economic benefits of AUD $4.35 million if 75% cost reduction is assumed; if 25% cost reduction is assumed, the savings decrease to AUD $1.71 million.

Yorobe (2006), Yorobe and Laude (2007), and Bayer, Norton, and Falck-Zepeda (2008) are the first to use the economic surplus model to estimate the impact of GM papaya in the Philippines. Yorobe (2006) used a small open economy framework to estimate the impacts of PRSV-resistant papaya. He found that PRSV-resistant papaya could reduce pesticide cost by 21%, and the cost of harvesting labor and seed cost would increase by 3% and 25%, respectively. Although the total cost of papaya production would increase by 8%, a significant increase (77%) in yield results in a 38% reduction of cost per kilogram. For an ex-ante analysis over a 15-year period, Yorobe found that producer surplus would increase by PhP 19.82 billion. Under this framework, consumer surplus is unchanged. By including incurred research costs of PhP 6.4 million and assuming a 5% discount rate, the net present value (NPV) of the net benefit is PhP 11.68 billion. Yorobe and Laude (2007) assumed a closed-economy model and estimated that the impacts of PRSV-resistant papaya on consumer surplus would be higher (PhP 5.61 billion) than the impact on producer surplus (PhP 4.21 billion). By including the costs of technology development and regulatory costs such as biosafety regulation, total benefits of PRSV papaya still outweigh the costs, providing the NPV of the net benefit of PhP 4.13 billion.

By assuming a small open economy model built upon Yorobe and Laude (2007), Bayer et al. (2008) estimated that the cost of compliance with biosafety regulations would be $248,500 USD, including contained laboratory and screen house testing, confined field trials, multi-location field trials, and other commercialization costs. Incorporating the research costs ($120, 370 USD) and regulatory costs, the NPV of net economic surplus would be $90.76 million USD at a 5% discount rate.

Economic assessment of GM papaya in Thailand has been nearly neglected. The Foreign Agricultural Service in Thailand (USDA, 2005) evaluated economic benefits of PRSV-resistant GM papaya in Thailand by collecting primary data from 122 farmers, 83 villagers, 20 collectors and wholesalers, 41 restaurant owners, 18 manufacturers and exporters, and from in-depth interviews with 11 government officers, lecturers, and researchers. This study assumed that the yield will improve from 17.44 to 262 tons/hectare if farmers were to adopt GM papaya. These numbers were obtained from interviewing the general director of DOA, who claimed that the average yield of papayas nation-wide decreased by 50% down to 17.44 tons/hectare due to PRSV infestation. Based on five different regions, five types of production systems, and types of fruits at the time of sales (green or ripe), the study compared farmers' income from growing GM vs non-GM variety. The estimate of average gross income across regions after adopting GM papaya was 1.43 million baht/hectare/crop compared to 94.36 thousand baht/hectare/crop for a non-GM variety. The estimate of net income over total initial investment of GM papaya would be 1.92 million baht/hectare/crop, compared to 87 thousand baht/hectare/crop for the non-GM variety, assuming that the price of GM papaya is the same as the price of non-GM.

The USDA study of GM papaya in Thailand (2005) estimated the farm-level impacts from adopting GM papaya—mainly income effects—by comparing annual costs and benefits of two alternative varieties. However, it did not take into account the impact on equilibrium price nor the impact over time; the study also did not cover the welfare distribution effect. Thus, it does not represent total economic effects. Our ex-ante analysis makes assumptions based on scientific data and the economic environment in Thailand as well as evidence from studies in other countries. The aggregate economic surplus impact of GM papaya is measured considering the rate and time of adoption during the study period.

Theoretical Framework

Alston, Norton, and Pardey (1998) suggested several approaches to evaluate agricultural technology. Despite criticism of the economic surplus approach (including measurement errors, general equilibrium effects, ignoring transaction costs, and externalities), its use is still justified when appropriate assumptions about impacts of research are made. The economic surplus model is also more advantageous than cost-benefit analysis and economometric models since it does not assume either perfectly inelastic or perfectly elastic supply or demand (Alston et al., 1998). In addition, the economic surplus calculation incorporates international price effects and distributional effects, unlike the cost-benefit analysis. For the ex-ante analysis in this article, we adopt a partial equilibrium model due to the limited information on dynamic linkages between sectors.

Since less than 2% of papaya production is exported, and there is no data on the imports, it is assumed that Thailand will continue to be a small net exporter of papaya. Since the share of exports from Thailand in the world market is less than 2%, a small exporting economy model is assumed in Scenarios 1 and 2. A closed economy model is assumed in Scenarios 3 and 4 under the assumption that GM papaya is not accepted in export markets. Figure 1 illustrates the changes in economic surplus from the adoption of GM papayas in a small exporting country. The adoption of GM papaya will shift the supply curve downward from S_0 to S_1, and the domestic demand curve of papayas is assumed to remain unchanged. The price of papaya is determined

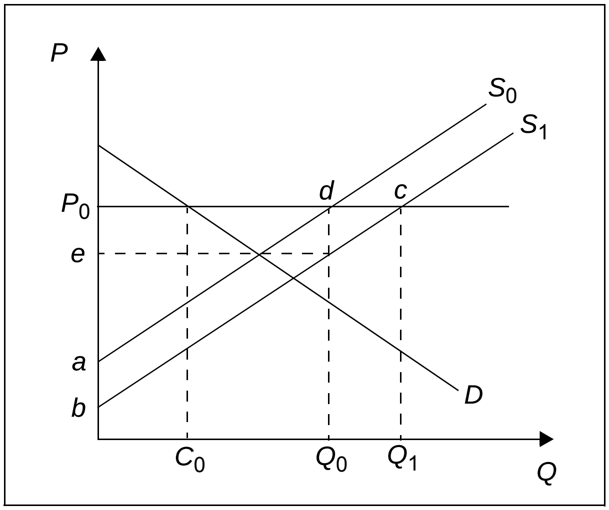

Figure 1. Changes in economic surplus from GM papaya adoption in a small exporting country.
Note. Adopted from Alston et al. (1998, p. 227).

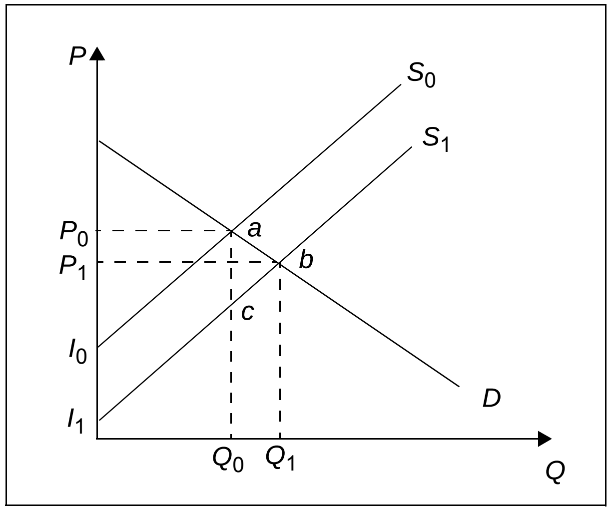

Figure 2. Changes in economic surplus from GM papaya adoption in a closed economy.
Note. Adopted from Alston et al. (1998, p. 209).

by the world market at P_0 and will not change because of the increasing supply in Thailand. Consumer surplus thus remains constant, whereas, producer surplus increases equal to the area *abcd*. In this case, Thailand could increase its exports to $Q_1 - Q_0$ if GM papaya is accepted in the export markets.

In this analytical framework, the domestic market is assumed to be homogeneous. In other words, consumers cannot distinguish between GM and non-GM papayas. Even though labeling is required for GM products,[1] it only covers soybeans and maize and does not cover products sold by small vendors. Fresh papaya is commonly sold in fresh markets by small vendors or sold as prepared dishes at food stalls or restaurants, so the labeling regulation will not be able to identify GM papaya sold in the domestic market. It is also assumed that loss of the export market is immaterial in this framework since most papaya is sold in the domestic market. In addition, China, which is the largest export market of papaya from Thailand (it accounts for more than 90% of total papaya exports) does not oppose GM products.

Figure 2 illustrates an alternative closed economy model, assuming that GM papayas will only affect the domestic market because exports will be lost. Under this assumption, the price of GM and non-GM papayas are assumed to be the same for the same reasons as homogeneous markets mentioned above. The adoption of GM papaya will shift the supply curve downward from S_0 to S_1; whereas, the demand curve of papayas remains unchanged. The price of papaya will drop from P_0 to P_1. As a result, consumer surplus increases equal to the area P_0abP_1, the change in producer surplus is equal to the area $P_1bI_1 - P_0aI_0$, and total surplus increases to the area I_0abI_1.

Methodology

To measure the change in economic surplus, Dynamic Research Evaluation for Management (DREAM) software is used based on Alston et al. (1998). For the small open economy scenarios (1 & 2),

$$\Delta PS_t = \Delta TS_t = P_0\, Q_0\, K_t\, (1 + 0.5K_t\, \varepsilon), \qquad (1)$$

where ΔPS_t is the change in producer surplus in year t, ΔTS_t is the change in total surplus in year t, P_0 is the world price, K_t is the proportional supply shift in year t = $(P_0 - e)/P_0$, and ε is the supply elasticity;

$$K_t = \{[E(Y)] / \varepsilon - [E(C)] / [1 + E(Y)]\}\, pA_t\, (1–\delta_t), \qquad (2)$$

where K_t is the proportionate downward shift in the supply curve in period t due to GM papaya adoption, $E(Y)$ is the expected proportionate yield change per hectare, $E(C)$ is the proportionate change in variable input costs per hectare to achieve the expected yield change, p is the success rate or the probability that GM papaya will achieve the expected yield, A_t is the adoption rate (pro-

1. *The Minister of Health announcement in 2002 of the GM labeling regulation requires that foods must be labeled if they contain ingredients derived from GM soybeans and maize in the top three components by weight, representing more than 5% of the total weight, and have more than 5% GM of each ingredient.*

Table 2. Assumptions of parameters used.

	Small open economy		Closed economy	
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Production quantity, Q_0 (ton)	220,805	220,805	220,805	220,805
Annual production area growth (%)	0.00	3.93	0.00	3.93
Current yield (ton/ha)	12.44	12.44	12.44	12.44
Price, P_0 (baht/ton)	5,482	5,482	5,482	5,482
Export volume, $Q_0 - C_0$ (ton)	2,273[a]	2,273[a]	0	0
Consumption quantity, C_0 (ton)	218,532	218,532	220,805	220,805
End of period GM papaya yield (ton/ha)	66.4	66.4	66.4	66.4
% yield increase, $E(Y)$	495	495	495	495
% cost reduction, $E(C)$	0	0	0	0
Supply elasticity, ε	0.8	0.8	0.8	0.8
Demand elasticity, η	∞	∞	-0.4	-0.4
Maximum adoption level (%)	80	80	80	80
R&D lag to first adoption (years)	3	3	3	3
Lag to 80% adoption (years)	10	10	10	10

Note. Data from Ministry of Agriculture and Cooperatives, Department of Agricultural Extension (2007).
[a] *Data from FAO (2007).*

portional area of GM papaya to total papaya production area in year t), and δ_t is the rate of annual depreciation of GM papaya (reduction of expected yield) in year t.

For the closed economy scenarios (3 & 4),

$$\Delta CS_t = P_0 Q_0 Z_t (1 + 0.5 Z_t \eta) \quad (3)$$

$$\Delta PS_t = P_0 Q_0 (K_t - Z_t)(1 + 0.5 Z_t \eta) \quad (4)$$

$$\Delta TS_t = \Delta CS + \Delta PS = P_0 Q_0 K_t (1 + 0.5 Z_t \eta) \quad (5)$$

$$Z_t = K_t \varepsilon / (\varepsilon + \eta), \quad (6)$$

where ΔCS_t is the change in consumer surplus in year t, Z_t is the reduction in price relative to the price prior to GM papaya adoption in year t, and η is the absolute value of the demand elasticity.

In this framework, the impacts are assumed to accrue for 10 years after first adoption, which takes place in Year 3. The net present value (NPV) is calculated from the annual surplus as follows:

$$NPV = \sum_{t=0}^{T} \Delta TS_t / (1 + r)^t, \quad (7)$$

where r is the discount factor.

The analysis includes the following four scenarios.

1. small exporter economy, current production area (2002-06 average)
2. small exporter economy, area expansion to pre-PRSV infestation levels (1997-2001 average)
3. closed economy, current area (2002-06 average)
4. closed economy, pre-PRSV infestation area (1997-2001 average)

Assumptions

Table 2 summarizes parameters assumed in each scenario. In all scenarios, it is assumed that if farmers adopt GM papaya, they will achieve the expected yield and there is no yield depreciation after each crop ($\delta_t = 0$) since no depreciation has been observed for other commercialized transgenic crops. The discount factor is assumed to be 5%. A three-year R&D lag to initial adoption is assumed because PRSV GM papaya varieties are available, but still need to pass biosafety field testing and time for seed propagation. Given that the potential yield of GM papaya is the same as Khakdam Thapra, 66.4 tons/hectare (Prasartsri & Chaikietiyod, n.d.), and the average yield of current papaya production during 2002-2006 is 12.44 tons/hectare (Ministry of Agriculture and Cooperatives, Department of Agricultural Extension, 2007), the expected yield improvement is assumed to be 495%. Although Khakdam Thapra is PRSV-resistant, it still gives a lower yield than GM papaya in field trials. Although the percentage yield improvement is greater than other studies, it is much less than what was assumed in the USDA's study of GM papaya in Thailand.[2] In addition, this number is based on controlled field trial evidence, which is the only reliable information to date. It is assumed that there is no cost savings since most current papaya growers do not use either pesticides or herbicides, which is similar to what Brookes and Barfoot (2008) found. In addition, the costs of GM and non-GM seeds are assumed to be the same because there is no anticipated technology fee or seed premium charged by the government.

The current national production (2002-06 average = 220,805 tons) is assumed for the beginning period in all scenarios. While the total area planted to papaya, (i.e., the potential adoption area) is assumed to remain at the current level (2002-06 average = 17,751 ha) in Scenarios 1 and 3, a higher end-of-period level is assumed in Scenarios 2 and 4. It is believed that GM papaya could result in an expanding area, particularly where there is heavy PRSV infestation. Thus, the 1997-2001 average production area (pre-PRSV infestation) is used to calculate the potential production at the maximum adoption area. This area expansion results in a compound annual production growth rate of 3.93% in Scenarios 2 and 4. The average farm price between 2002 and 2006 is 5,482 baht/ton (Ministry of Agriculture and Cooperatives, Department of Agricultural Extension, 2007). The consumption level is calculated from the current export volume (2002-05 average; FAO, 2007).

Since papaya is commonly consumed as both a fresh fruit and as a salad vegetable, this study assumes the price elasticity of demand for papaya is equal to the average between the observed price elasticity of demand for fruits and that for vegetables. Isvilanonda and Plangpraphan (1992) found that the price elasticity of demand for fruit is -0.711 and that for vegetables is -0.167; thus, the price elasticity of demand for papaya is assumed to be -0.4. Although Bayer et al. (2008) assumed unit elasticity of demand for papaya in the Philippines, and Paris et al. (2002) assumed the elasticity of demand for papaya in Thailand is -1.5, this study assumes that the demand for papaya in Thailand is relatively more inelastic since green papaya is a specific ingredient for papaya salad, which is widely popular in all regions. The price elasticity of supply for papaya is assumed at 0.8, which is equal to what Bayer et al. (2008) and Yorobe (2006) assumed in their studies. In addition, the production of papaya does not require a large component of fixed inputs; the supply elasticity is relatively inelastic (Alston et al., 1998).

While Bantilan (1992) assumed a 100% adoption ceiling for GM papaya in the Philippines, Yorobe (2006) and Bayer et al. (2008) assumed a lower adoption level at 90% in six years and 80% in five years. Based on those studies and reports of several interviews with papaya farmers in Thailand, this study assumes a conservative ceiling adoption level of 80% within 10 years. Although no studies have analyzed farmers' adoption in Thailand, a large number of farmers are willing to adopt GM papaya (Biotechnology and Biosafety Information Center, 2006; USDA, 2005) since PRSV is a very severe problem in papaya production, and a PRSV-resistant variety could improve production competitiveness. The incremental increase of the area of GM papaya adoption is assumed to have a sigmoid form.

Results

Estimates of economic surpluses are shown in Table 3. Under small exporting economy scenarios, total economic surplus accrues only to producers. Consumer surplus remains constant since the price remains at the world market price. However, consumers may still benefit from improved quality, more stability, and continuity of papaya supply. In addition, if GM papayas are adopted in other major exporting countries, consumers will eventually benefit from a decrease in world price. Under the small open economy, producers will benefit from yield improvement or unit-cost reduction. Comparing the open and closed economy under the same production area (Scenarios 1 and 3; Scenarios 2 and 4), consumers benefit not only from improved quality, but also from a price reduction. However, producers benefit less under a closed economy than under a small open economy because higher supply will suppress the domestic price and generate less revenue than if price was fixed at the world market. Even though the consumer surplus becomes larger, a smaller total production level results in a smaller total surplus in the closed economy model, as compared to the small exporting model.

The benefits under a larger adoption area are greater than those under a small adoption area (Scenarios 1 and 2; Scenarios 3 and 4). In addition, the benefits to consumers are larger than the benefits to producers under the closed economy model. Given that the price elastic-

2. *Gonsalves et al. (2004) found 76% in Hawaii; Brookes and Barfoot (2008) found 16-50% in the US; Bantilan (1992) assumed 350% in the Philippines; Yorobe (2006) and Bayer et al. (2008) assumed 77% in the Philippines. USDA (2005) assumed 1400% in Thailand.*

Table 3. Economic surplus of GM papaya adoption (million baht).

Year	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	∆*PS*	∆*CS*	∆*TS*	∆*PS*	∆*CS*	∆*TS*	∆*PS*	∆*CS*	∆*TS*	∆*PS*	∆*CS*	∆*TS*
2009	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0
2012	100	0	100	112	0	112	33	65	98	34	68	102
2013	260	0	260	303	0	303	82	165	247	87	174	261
2014	683	0	683	823	0	823	204	407	611	219	438	657
2015	1,754	0	1,754	2,186	0	2,186	471	942	1,413	520	1,039	1,559
2016	3,988	0	3,988	5,138	0	5,138	949	1,898	2,847	1,082	2,164	3,246
2017	7,105	0	7,105	9,479	0	9,479	1,537	3,074	4,611	1,819	3,639	5,458
2018	9,784	0	9,784	13,540	0	13,540	2,006	4,012	6,018	2,459	4,917	7,376
2019	11,349	0	11,349	16,308	0	16,308	2,270	4,540	6,809	2,871	5,743	8,614
2020	12,079	0	12,079	18,033	0	18,033	2,391	4,782	7,173	3,115	6,229	9,344
2021	12,386	0	12,386	19,215	0	19,215	2,441	4,883	7,324	3,272	6,544	9,816
NPV	35,258	0	35,258	50,164	0	50,164	7,396	14,792	22,188	9,192	18,384	27,575

Note. $1 USD = 34 baht (June 2009)

ity of both demand and supply are constant and inelastic, the larger supply elasticity (in absolute value) relative to demand results in higher consumer surplus than producer surplus. The distribution of benefits is similar to that found by Yorobe and Laude (2007)—that consumers gain more than papaya producers in the closed economy model in the Philippines. Our results found that consumers gain twice as much as producers.

When the total production area is assumed at the current 2002-2006 average in Scenario 1, the total discounted value of economic surplus is 35.3 billion baht ($1.04 billion USD). If the production area grows at 3.93% per year to reach pre-PRSV levels, the NPV of GM papaya adoption is about 50.164 billion baht ($1.48 billion USD). Compared to the small open economy model, under the closed economy assumption, both consumers and producers would benefit from this technology. The NPV of total economic surplus suggests that GM papaya will be generating about 22.2 billion baht ($0.65 billion USD) when assuming current planted area and will generate 27.6 billion baht ($0.81 billion USD) when assuming the larger planted area in Scenario 4. The total benefit is smaller in a closed economy scenario than in an open economy model for a given production level, but consumers will benefit largely from the adoption of GM papayas even if the export market vanishes.

Conclusions

The papaya industry has been severely affected by PRSV, with national production in 2007 falling to half the level of 1999. GM papaya varieties have been developed, suggesting that seeds could be made available to farmers within a relatively short time. Informal evidence suggests that farmers in Thailand would be willing to adopt GM varieties once they are commercially available. GM crops have already provided large economic benefits in several countries of the world, and hold great promise for delivering large benefits in Thailand once biosafety protocols are established. If Thailand successfully adopted GM papayas, the majority of benefits would accrue to small farmers who face severe PRSV problems. Even though consumers will not benefit from a price reduction when excess supply is exported to foreign markets, they could still benefit from a stable and continual supply as well as higher quality.

If Thailand lost its papaya export markets due to GM papaya adoption, domestic consumers will benefit from better quality products at a lower price even though the total economic surplus is smaller compared to in the small-exporting-country assumption. This study does not cover the cost of research and development of the GM papaya variety since those investments have already been made and commercially viable varieties are available. The results show that if GM papaya is approved, Thailand could benefit from this technology.

This economic impact assessment will compliment the environmental and social impact evaluation of GM technology in Thailand.

References

Alston, J.M., Norton, G., & Pardey, P.G. (1998). *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting (*2nd Edition). Wallingford, UK: CAB International.

Angyurekul, N., & Tugsinavisuth, S. (2003). *Papaya production and marketing economic program* [in Thai]. Center for Applied Economics Research, Kasetsart University, Bangkok, Thailand.

Bantilan, C.S. (1992). *A project development assessment of CS1/1991/007: Control of papaya ringspot in the Philippines by development of papaya ringspot virus resistant hybrids* (Unpublished Analysis Incorporated in the ACIAR Document for Project CS1/1991/007). Canberra: Australian Centre for International Agricultural Research.

Bayer, J.C., Norton, G.W., & Falck-Zepeda, J. (2008, July). *The cost of biotechnology regulation in the Philippines*. Paper presented at the American Agricultural Economics Association Annual Meeting, Orlando, Florida. Available on the World Wide Web: http://ageconsearch.umn.edu/bitstream/6507/2/469973.pdf.

Biotechnology and Biosafety Information Center. (2006, June 14). *News update* (in Thai). Available on the World Wide Web: http://www.safetybio.com/news/news_board.asp.

Brookes, G., & Barfoot, P. (2008). Global impact of biotech crops: Socio-economic and environmental effects, 1996-2006. *AgBioForum*, *11*(1), 21-38. Available on the World Wide Web: http://agbioforum.org/v11n1/v11n1a03-brookes.htm.

Davidson, S.N. (2006). *The genetically modified (GM) PRSV resistant papaya in Thailand: A case study for the agricultural biotechnology policy development in the GMS subregion.* (Prepared for *Strengthening Capacity and Regional Cooperation in Advanced Agricultural Science and Technology in the Greater Mekong Subregion*). Manila, The Philippines: The Asian Development Bank.

Food and Agricultural Organization of United Nations (FAO). (2007). *FAOSTAT trade data* [database]. Accessed on May 5, 2008 from http://faostat.fao.org/site/567/default.aspx.

Gonsalves, C., Lee, D.R., & Gonsalves, D. (2004, August-September). *Transgenic virus-resistant papaya: The Hawaiian 'rainbow' was rapidly adopted by farmers and is of major importance in Hawaii today* (APSnet Feature). St. Paul, MN: American Phytopathological Society. Available on the World Wide Web:http://www.apsnet.org/online/feature/rainbow.

Isvilanonda, S., & Plangpraphan, J. (1992). *Demand for and supply of horticulture in Thailand* [in Thai] (Year-end seminar paper). Bangkok: Thailand Development and Research Institute.

Ministry of Agriculture and Cooperatives, Department of Agricultural Extension. (2007). *Agricultural production statistics report*. Bangkok, Thailand: Author.

Paris, T., Carambas, N., McMeniman, S., & Lubulwa, G. (2002). *Impact assessment of twenty-one ACIAR-supported projects based at the university of Philippines, Los Banos (1983-1995)* (Impact Assessment Program Working Paper Number 43). Canberra: Australian Centre for International Agricultural Research.

Prasartsri, V., & Chaikietiyod, S. (n.d.) *Khaekdum Thapra papaya tolerant to papaya ringspot virus*. Bangkok: Horticultural Research Institute of Thailand.

Sankula, S. (2006, November). *A 2006 update of impacts on US agriculture of biotechnology-derived crops planted in 2005*. Washington, DC: NCFAP. Available on the World Wide Web: http://www.ncfap.org/documents/2005biotechimpacts-finalversion.pdf.

Sankula, S., & Blumenthal, E. (2004). *Impacts on US agriculture of biotechnology-derived crops planted in 2003: An update of eleven case studies* (Final report). Washington, DC: National Center for Food and Agriculture Policy (NCFAP).

The Customs Department of Thailand. (2006). *Imports and exports statistics* [database]. Available on the World Wide Web: http://www.customs.go.th/Statistic/StatisticIndex.jsp.

US Department of Agriculture (USDA). (2005). *A study on the economic benefits of biotechnology papaya in Thailand on CD-ROM*. Bangkok: Author.

Yorobe, J.M. Jr. (2006). Ex ante economic impact assessment of the ring spot virus resistant papaya in the Philippines. In *Projected Impacts of Biotechnology Products in Indonesia and the Philippines* (ISAAA and ABSP-II Impact Study). Manila, The Philippines: ISAAA.

Yorobe, J.M. Jr., & Laude, T.P. (2007). *Costs and benefits of PRSV-resistant technology in the Philippines* (ISAAA and Agricultural Biotechnology Support Program II [ABSP-II] Impact Study). Manila, The Philippines: International Service for the Acquisition of Agri-biotech Applications (ISAAA).

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