Ann Reg Sci (2011) 46:455–468
DOI 10.1007/s00168-009-0322-7

ORIGINAL PAPER

Estimating the economic benefits of area-wide pest management: an extended framework with transport cost

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Received: 13 October 2008 / Accepted: 19 July 2009 / Published online: 13 August 2009

Abstract While transport cost is an important explanatory variable in determining trade patterns and flows, existing analyses have not yet considered it in evaluating the economic consequences of technical innovation such as area-wide pest management. In this paper, we extended Alston et al.'s (Science under scarcity: principles and practice for agricultural research evaluation and priority setting, 1995) framework by incorporating transport cost and applied the extended model to assess the Hawaii Area-Wide Fruit-Fly Integrated Pest Management Program. The study results indicate that ignoring transport cost could significantly overestimate the potential gains from this program and overestimate the proportion of the benefits obtained by producer. Hence, it is imperative to take into account the effects of transport cost in estimating the welfare consequences associated with the adoption of area-wide pest management, especially when such adoption causes substantial changes in production.

JEL Classification D61 · Q11 · Q13

1 Introduction

Many studies have examined the economic consequences associated with the adoption of a new pest control practice (Lichtenberg 1987; Adda et al. 2002; Timothy and Robert 2004). These studies vary by types of benefits, stakeholders, as well as analytical frameworks employed (see for example, Akino and Hayami 1975; Edwards and Freebairn 1984; Hoffmann et al. 1995). Among the array of conceptual frameworks in

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the literature, the interregional trade model developed by Alston et al. (1995), focusing on producer surplus and consumer surplus associated with a supply shift, is the most prominent one and has been extensively employed in empirical studies (Price et al. 2003). Using this general approach, many factors (i.e., demand and supply elasticities, market size, technical spillover, etc.) have been investigated concerning their welfare implications in the adoption of a production-enhancing technology (Frisvold et al. 1999; Falck-Zepeda et al. 2000; Frisvold et al. 2006). While transport cost has already been shown as an important explanatory variable in determining trade patterns and flows (Hummels 1999; Venables and Limao 2002; Martinez-Zarzoso et al. 2003; Mun and Nakagawa 2007), existing theoretical and empirical analyses for the assessment of the economic consequences of the adoption of a new pest control method have not yet considered it. In this paper, we extended Alston et al.'s framework by incorporating transport cost and applied it to estimate the welfare implications of transport cost in the adoption of an innovative pest management method—area-wide pest management—in a small, open economy.

Area-wide pest management, which is widely acclaimed to be the most effective way of controlling insect pests, is a new pest control approach against the total population of pests over a large geographic area (Lindquist 1998; Mumford 1998). In contrast to pest control practices on a farm-by-farm basis, area-wide pest management operates on a regional basis. Consequently, implementation of area-wide pest management could significantly affect the production and supply of pest-susceptible crops in the treated region and thereby alters the local market equilibrium. As a result, we ought to assess the welfare effects of area-wide pest management in an aggregate manner, and Alston et al.'s framework is suitable for this purpose.

To illustrate the importance of incorporating transport cost in the empirical analysis, we applied the extended analytical framework to evaluate the Hawaii Area-Wide Fruit-Fly Integrated Pest Management Program (HAW-FLYPM), a project attempting to suppress the population of fruit flies in the State of Hawaii. The evaluation results indicate that excluding transport cost would significantly overestimate the project's potential benefit and misallocate the entire benefit to Hawaii's producers. Therefore, it is paramount for policy-makers to take into account the effects of transport cost when evaluates the welfare consequences of implementing area-wide pest management.

2 The analytical framework

This study focuses on the potential economic gains from adoption of area-wide pest management in a small, open economy. The analytical framework consists of two markets: a small domestic market and a large distant market. The effect of implementing area-wide pest management by the domestic producers, which leads to an increase in domestic production, is modeled as a rightward shift in the domestic supply curve. The effects of such a supply shift are measured via changes in the market equilibrium price and quantity. The resulting welfare gains are then estimated based on these price and quantity effects in terms of producer surplus and consumer surplus. In practice, the market system involves many other agents besides producers and consumers. Wholesalers and retailers usually exist between producers and consumers. They would be

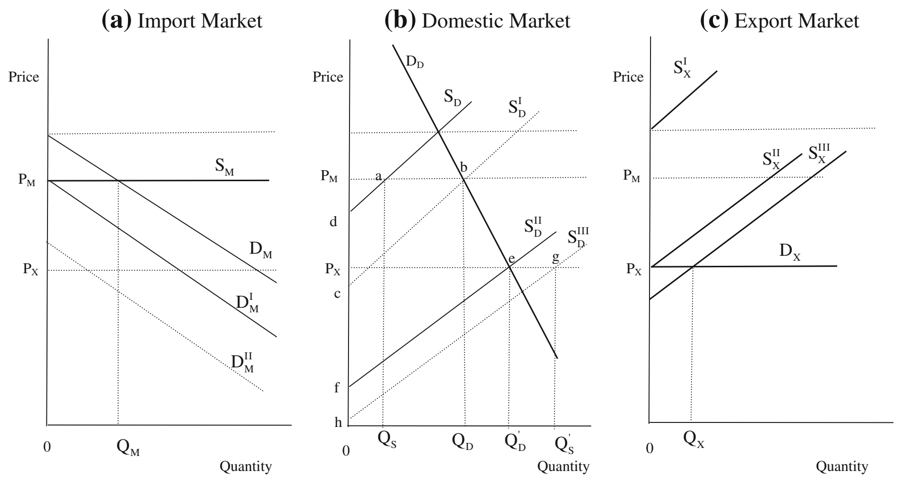

Fig. 1 The extended analytical framework with transport cost. **a** Import market, **b** domestic market, **c** export market

able to capture some of the potential benefits, depending on their market power as compared to those of the producers and consumers (Sexton 2000; Sexton and Zhang 2001). In the present study, we assume that the producers and consumers will capture the entire benefits. This simplification largely facilitates our analysis without altering the size of the potential benefits.

Figure 1 illustrates the extended analytical framework. Panels a, b, and c represent, respectively, the import, domestic, and export markets faced by domestic producers. D_D in Panel b represents the demand of domestic consumers. P_M represents the import price of the product from the distant market. P_X represents the export price of the domestic product to the distant market. Under the small-trader assumption, the import supply (S_M) and the export demand (D_X) can be represented by a horizontal straight line at prices P_M and P_X, respectively. The import demand is derived as the difference between the domestic supply (production) and the domestic demand at a given price. For example, if the domestic supply curve is S_D as in Panel b, the corresponding import demand curve will be D_M as in Panel a where Q_M equals $Q_D - Q_S$. Similarly, the export supply is derived as the difference between the domestic supply (production) and the domestic demand at a given price. For example, if the domestic supply curve is S_D^{III} as in Panel b, the corresponding export supply curve will be S_X^{III} as in Panel c where Q_X equals $Q_S' - Q_D'$.

The price and quantity effects of shifting the domestic supply curve are contingent on the trade status of the domestic market. Assume the domestic market is a net importer. The domestic supply then can be represented by S_D in Panel b and the domestic price equals P_M. The import demand curve associated with S_D thus can be derived as D_M in Panel a. A rightward shift of S_D will cause a leftward shift of D_M, i.e., the import demand decreases as the domestic supply increases. For example, if the domestic supply curve moves from S_D to S_D^I, the import demand curve will move from D_M to D_M^I accordingly. In this case, the domestic market remains as a net importer.

The increased domestic production simply replaces the imported product. The domestic price stays at P_M, and thus there will be no change in consumer surplus. The change in producer surplus can be measured by the area abcd as in Panel b. Shifting the supply curve beyond S_D^I will not involve the import market any more because domestic production will completely replace imported product beyond S_D^I, i.e., $Q_M = 0$.

If the domestic market is autarky, the domestic supply curve might be represented by S_D^I as in Panel b. In this case, a rightward shift of S_D^I will cause the domestic price to decline until it reaches P_X under the small-trader assumption. Within the region $P_M P_X$, the increased domestic supply (production) will be absorbed by domestic consumers. In other words, the domestic market remains autarky in the region $P_M P_X$. Shifting the domestic supply curve within this region affects price as well as quantity. For example, if the supply curve shifts from S_D^I to S_D^{II}, the associated change in consumer surplus can be measured by the area $P_M$beP_X in Panel b and the change in producer surplus can be measured by the area $P_X$ef minus the area P_M bc in Panel b.

Once the domestic price reaches the export price (P_X), it will stay at this price level for any rightward shift of the domestic supply curve beyond S_D^{II} under the small-trader assumption, because the excess domestic production will be absorbed by the export market at a constant price, P_X. Consequently, there will be no price effect and changes in consumer surplus in the export region. For example, if the domestic supply curve moves from S_D^{II} to S_D^{III} in Panel b, the export supply curve will move from S_X^{II} to S_X^{III} accordingly in Panel c and the quantity of export, Q_X, will equal the excess supply in the domestic market, $Q'_S - Q'_D$, as shown in Panel b. The change in producer surplus in this case can be measured by the area eghf in Panel b.

The difference between P_M and P_X can be considered as the transport charge. As long as the transport cost is positive, i.e., $P_M - P_X > 0$, there will be an autarky region (i.e., see the region between P_M and P_X in Panels a, b, and c). If the new supply curve after shifting remains in this region, such a supply shift would lead to a reduction in the domestic price and thus benefit domestic consumers. However, if transport cost were ignored, the import price (P_M) will equal the export price (P_X) and the autarky region, $P_M P_X$, will vanish. In this case, there will be no price effect regardless of the trade status of the domestic market. In other words, domestic consumers will never benefit from the adoption of area-wide pest management. Incorporation of transport cost in assessment is crucial for estimating the distribution of the potential benefits among producers and consumers.

In the next two sections, we derive the expressions for computing the price and quantity effects as well as the resulting economic benefits.

2.1 Changes in market equilibrium

Assuming the product under investigation can be traded between the domestic and distant markets without any trade barrier, the supply and demand system in the domestic market can be described by expressions (1) to (4) as follows:

$$\text{Domestic demand: } Q_D = D(P) \tag{1}$$

$$\text{Domestic supply: } Q_S = S(P, K) \tag{2}$$

$$\text{Trade relation: } Q_T = F(P, P_X, T_M, T_X) \tag{3}$$

$$\text{Market clearing condition: } Q_T = Q_S - Q_D \tag{4}$$

where Q_D and Q_S are, respectively, quantity demanded and supplied by the domestic market. P and P_X are domestic and export prices. T_X and T_M are, respectively, transport cost from the domestic market to the distant market and transport cost from the distant market to the domestic market. The export price of the domestic product, P_X, equals the prevailing distant market price (P_F) minus the export transport charge (T_X) under the small-trader assumption, i.e., $P_X = P_F - T_X$.[1] Q_T is quantity traded between the two markets, and K is the supply shifter, measuring the size of the rightward shift of the supply curve.

Let ρ denote the difference between the prevailing domestic price and the export price, i.e., $\rho = P - P_X$. Under the small-trader assumption, trade relation expression (3), can be further specified as follows:

$$\text{if } \rho = T_X + T_M, \quad Q_T < 0 \tag{3a}$$

$$\text{if } \rho = 0, \quad Q_T > 0 \tag{3b}$$

$$\text{if } 0 < \rho < T_X + T_M, \quad Q_T = 0 \tag{3c}$$

Expression (3a) is an export demand relation ($Q_T > 0$);[2] expression (3b) is an import demand relation ($Q_T < 0$); and when the domestic is autarky ($Q_T = 0$), trade relation vanishes.[3]

The impacts of a supply shift can be expressed by differentiating Eqs. (1)–(4), which yields

$$Q_D^* = \eta P^* \tag{5}$$

$$Q_S^* = \varepsilon(P^* + \gamma) \tag{6}$$

$$Q_T^* = e\rho^* \tag{7}$$

$$Q_D^* = (Q_S/Q_D)Q_S^* - (Q_T/Q_D)Q_T^* \tag{8}$$

where the asterisked variables indicate relative change (e.g.,$Q_D^* = dQ_D/Q_D$). η and ε are the domestic demand elasticity and the domestic supply elasticity, respectively. γ represents the relative vertical shift in the supply curve caused by enhanced productivity due to area-wide pest management, i.e., the shift in the price direction holding quantity constant. The relative vertical shift can be expressed as the relative horizontal

[1] The relation of the domestic and distant prices can be described as follows: (1) domestic market is an net importer, $P = P_F + T_M$; (2) domestic market is an net exporter, $P + T_X = P_F$; and (3) domestic market is autarky, $P + T_X > P_F > P - T_M$. If the export price, P_X, equals $P_F - T_X$, domestic producers will be willing to export their products.

[2] When the domestic market is a small importer, $P - P_F = T_M$. Substitute $\rho = P - P_X$ and $P_X = P_F - T_X$ into this equation yields $\rho = T_X + T_M$.

[3] When the domestic market is autarky, $P + T_X > P_F > P - T_M$. Substitute $\rho = P - P_X$ and $P_X = P_F - T_X$ into this expression yields $0 < \rho < T_X + T_M$.

shift divided by the supply elasticity.[4] For instance, if area-wide pest management increases production (and supply) by 40% and $\varepsilon = 0.8$, the implied vertical shift will be 50%, i.e., $\gamma = 0.50$. ρ^* in Eq. (7) equals $P^* P/\rho$. It measures how the change in the difference of the domestic and export price (ρ) affects the trade quantity and direction. $e = (\partial Q_T/\partial\rho)(\rho/Q_T)$ in Eq. (7) and can be interpreted as the elasticity corresponding to the trade relation. e will equal $-\infty$ when $\rho = T_X + T_M$ (an importer), and will equal $+\infty$ when $\rho = 0$ (an exporter). When $0 < \rho < T_X + T_M$ (autarky), e will equal zero.

The relative change in the domestic price due to a supply shift can be determined by solving Eqs. (5)–(8) simultaneously, which yields

$$P^* = [(Q_S/Q_D)/(\eta - (Q_S/Q_D)\,\varepsilon + (Q_T/Q_D)e(P/\rho))]\,\varepsilon\gamma \tag{9}$$

Equation (9) is a generalized expression of the price effect caused by a supply shift for various trade statuses. For example, under autarky ($Q_T = 0$ and $e = 0$), expression (9) is reduced to

$$P^* = \varepsilon\gamma/(\eta - \varepsilon) \tag{10}$$

Substituting Eq. (10) into expressions (5) and (6) yields:

$$Q_D^* = \varepsilon\gamma\eta/(\eta - \varepsilon) \tag{11}$$
$$Q_S^* = \varepsilon[\varepsilon\gamma/(\eta - \varepsilon) + \gamma] \tag{12}$$

On the other hand, if the domestic market in question is a small importer or exporter, Eq. (9) reduces to $P^* = 0$. In this instance, Eqs. (5) (6) and (8) can be rearranged into

$$Q_S^* = \varepsilon\gamma \tag{13}$$
$$Q_D^* = 0 \tag{14}$$
$$Q_T^* = (Q_S/Q_T)\,\varepsilon\gamma \tag{15}$$

In the absence of transport cost, the domestic market can only be either a small importer or a small exporter. Expressions (13)–(15) then can be used to estimate the quantity effects. Conversely, in the presence of transport cost, the domestic market might turn from an importer into autarky (or an exporter), or from autarky into an exporter. In these three scenarios, expressions for computing the price and quantity effects change when the trade status of the domestic market changes. For example, if the domestic market turns from an importer into autarky, we ought to use expressions (13)–(15) to calculate the quantity effect in the importer region and use expressions (10)–(12) to

[4] The vertical shift parameter is derived by expressing Eq. (2) in percentage changes, i.e., $Q_S^* = \varepsilon P^* + \alpha$ where $\alpha = \varepsilon_K K^*$ is the horizontal shift parameter. Setting $Q_S^* = 0$ yields $P^*\,|_{Q*} = 0 = -\alpha/\varepsilon = \gamma$, the relative change in price when supply shifts along a vertical demand curve. Note that for a rightward supply shift, $\alpha > 0$, which implies $\gamma < 0$. To simplify interpretation of results we ignore the sign and interpret γ as the downward shift in supply, i.e., the relative reduction of price holding quantity constant.

calculate the price and quantity effects in the autarky region. The overall price and quantity effects are the sum of the two effects in their associated regions.

2.2 Changes in producer surplus and consumer surplus

After obtaining the price and quantity effects along with the vertical shift parameter, we can use Alston et al.'s formulas to compute the associated changes in consumer and producer surplus. To use their formulas, we have to retain a critical assumption—the shift of the supply curve is parallel. The specification concerning the pattern of a supply shift (parallel or pivotal) is somewhat controversial in the literature. A sequel of studies (Alston and Wohlgenant 1990; Wohlgenant 1997) has pointed out that in general it is impossible to *a priori* qualify the pattern of a shift in the supply curve caused by adopting a production-enhancing (or cost-reducing) technology such as a more effective pest control technique. Many factors—such as the spatial allocation of producers, the adoption rate by producers, the cost structure of production, the industrial structure, and the entry and exit condition for potential and existing producers—can influence the resulting pattern. For an *ex ante* assessment, necessary information to make an appropriate prediction of the shift pattern is usually unavailable. Despite of the controversy, assuming a parallel shift has become the common practice in empirical studies (Price et al. 2003), because it has several analytical advantages.

The specific formulas for estimating changes in consumer surplus and producer surplus based on the price and quantity effects can be described as follows:

$$\text{Changes in consumer surplus: } \Delta\text{CS} = \text{PQ}_\text{D} P^*(1 + 0.5 Q_\text{D}^*) \quad (16)$$

$$\text{Changes in producer surplus: } \Delta\text{PS} = \text{PQ}_\text{D}(\gamma - P^*)(1 + 0.5 Q_\text{S}^*) \quad (17)$$

$$\text{Changes in total surplus: } \Delta\text{TS} = \text{PQ}_\text{D}[(\gamma - P^*)(1 + 0.5 Q_\text{S}^*) + P^*(1 + 0.5\text{Q}_\text{D}^*)] \quad (18)$$

Under the small trader assumption, $Q_\text{S}^* - Q_\text{D}^* > 0$ holds for a rightward supply shift. We can verify that $\Delta\text{TS}|_{P^*>0} > \Delta\text{TS}|_{P^*=0}$, confirming that the total benefits would be overestimated by excluding the effects of transport cost.

3 Application

Four fruit-fly species—melon fly, Mediterranean fruit fly, oriental fruit fly, and solanaceous (Malaysian) fruit fly—have wreaked havoc in the State of Hawaii for more than three decades and have greatly affected the profitability and sustainability of fruit and vegetable production statewide. The Hawaii Area-Wide Fruit-Fly Integrated Pest Management Program (HAW-FLYPM) launched in 2001 is an attempt to suppress the population of fruit flies to economically manageable levels, using multiple cutting-edge suppression technologies. Based on several farm experiments so far, this project has achieved dramatic success against these insects. However, the possible welfare implications of implementing HAW-FLYPM statewide have yet to be determined. In particular, transport cost is a deterministic factor influencing the supply of agricultural products in Hawaii (Yu and Leung 2009). We, therefore, applied the extended framework as described previously to estimate the potential economic benefits arising from HAW-FLYPM to Hawaii's producers and consumers. This case study vividly illustrates the significance of transport cost in evaluating an area-wide pest management project.

The analytical framework in this application consists of the Hawaii market and the U.S. mainland market. Eight major commercial fruit-fly-susceptible crops in the State of Hawaii for which the small open market assumption is thought to be appropriate and applicable are investigated.[5] These eight crops—bitter melon, cucumber, eggplant, green pepper, pumpkin, Italian squash, tomato, and watermelon—are grown locally but are not of sufficient quantity to meet the entire local demand. As a result, depending on the magnitude of damage suppression, three possible scenarios could emerge due to the implementation of HAW-FLYPM. The first scenario is that the increased production replaces a part of the imports and Hawaii remains as a net importer. The second scenario is that the excess production replaces all the imports and Hawaii becomes autarky. The third scenario is that a considerable level of damage suppression makes Hawaii's products even competitive in the U.S. mainland market and Hawaii becomes a net exporter.

We constructed a spreadsheet model to calculate the aggregate benefit of HAW-FLYPM, which equals the sum of the individual benefit from each of the eight products. In other words, we assume consumption and production of the eight crops are independent. If products are related in either consumption or production, or both, the overall welfare impacts due to a particular shift in one product ought to be measured in a more general equilibrium fashion, which, however, would become unnecessarily complicated to be practical for the present application.

3.1 Assumption and data

The key parameters affecting our estimates are the own price elasticity of demand, the elasticity of supply, and the size of supply shift. However, there are no empirical estimates of demand and supply elasticities of the eight crops under investigation in Hawaii. Specific empirical estimates of demand elasticities at the national level are available only for four crops: cucumber, green pepper, tomato, and watermelon (You et al. 1998). The average demand elasticity of U.S. fresh vegetables (You et al. 1998), 0.24, therefore, is adopted for the remaining four crops: bitter melon, eggplant, Italian squash, and pumpkin. Meanwhile, the supply elasticity is assumed to be 0.8 for the eight crops, which is a close approximation of the long-run supply elasticity of U.S.

[5] Only one fruit-fly-susceptible crop, papaya, is left out as it does not satisfy the small open market assumption. For an interregional trade model consisting of two large markets, the welfare impacts caused by a supply shock in a single market will depend on the supply and demand systems in the domestic and distant markets together. Subsequently, we have to obtain the information regarding the elasticities of supply and demand and the original equilibrium prices and quantities in the domestic market as well as the distant market. While the impact for papaya could be estimated with modest modifications in the present model when necessary information are obtained, the purpose here is to illustrate the application of the small open market case as developed in this paper.

Table 1 Average market supply of major Fruit-Fly susceptible crops in Hawaii, 2001–2003

Crops	Production 1,000 lb	Inshipment 1,000 lb	Total supply 1,000 lb	Hawaii price \$/lb	California price \$/lb	Demand Elasticity [a]
Bitter melon	223	40	263	0.80	0.67	−0.24
Cucumber	5, 533	432	5, 965	0.46	0.31	−0.30
Eggplant	867	438	1, 305	0.71	0.25	−0.24
Pepper, Green	3, 200	1, 957	5, 157	0.60	0.28	−0.25
Pumpkins	550	203	753	0.43	0.12	−0.24
Squash, Italian	1, 667	1, 036	2, 703	0.49	0.21	−0.24
Tomato	17, 500	2, 773	20, 273	0.55	0.29	−0.38
Watermelons	11, 233	2, 139	13, 372	0.25	0.12	−0.61

[a] You et al. (1998)
U.S. Department of Agriculture and Hawaii State Department of Agriculture

fresh fruits and vegetables (Huffman and McCunn 1996). Nonetheless, we conducted sensitivity analysis to test the robustness of the results against these somewhat imprecise parameters. The average damage reduction reported so far by Hawaii's growers due to HAW-FLYPM is about 30 percent (HAW-FLYPM Newsletter 2007), which is equivalent to at least a 40% increase in the original production, depending on the level of past crop damage.[6] We further assume that this change of production can be represented by a 40% rightward shift in the domestic supply curve and it will not lead to any structural change in the supply curve. In practice, the increased in local supply may not be able to replace the imported supply, particularly in the short term. For example, wholesalers and importers may have existing contracts with the mainland suppliers and thus would not be able to absorb the increased local supply instantaneously. Thus, we could consider the framework set forth is more for the intermediate and longer run situation. Furthermore, with increased productivity, growers may adjust their resource allocation which could affect their level of production and hence their scale economy. This could potentially cause a structural change in supply. However, we feel that for the present case, this effect is rather negligible.

Production quantities and prices are measured as averages for the 3 years from 2001 to 2003 (see Table 1). Average State of California fob shipping point prices are taken to be the estimated U.S. mainland market prices. Although actual imported products may come from various locations, the average fob shipping point price in the State of California is a good approximation, since it is generally used as the benchmark import price for the Hawaii market. We estimated transport cost based on the freight rate quoted by the Matson Navigation Company, which is the principal carrier of containerized freight between the U.S. Pacific Coast and Hawaii. The estimated

[6] The percent increase in production, α, can be expressed as $\alpha = [1 - (d - k)]/(1 - d) - 1$; where d is percent damage loss and k is percent suppression in damage loss ($d > k$). In our exercise, $k = 30\%$. So, $\alpha = 0.3/(1 - d)$ and $d > 30\%$. The lowest percent increase in production would occur when d approaches 30%, i.e., $\alpha \approx 40\%$. Hence, the original production would be enhanced by at least 40% based on the levels of damage suppression reported by Hawaii's growers ($k = 30\%$).

Table 2 Summary of estimated annual benefits ($1,000)

Crop	Baseline			Alternative scenario: no transport cost
	Producer surplus	Consumer surplus	Total surplus	Producer surplus
Bitter melon	48	39	87	107
Cucumber	326	775	1, 101	1, 527
Eggplant	369	0	369	369
Pepper, Green	1, 152	0	1, 152	1, 152
Pumpkins	131	7	138	142
Squash, Italian	490	0	490	490
Tomato	2, 614	2, 036	4, 650	5, 775
Watermelons	989	433	1, 422	1, 685
Total	6, 072	3, 252	9, 324	11, 140

Assume a 40% increase in the original production and a supply elasticity of 0.8

in-shipment rate for fresh vegetables and fruits is $0.124/lb. The estimated out-shipment rate for fresh vegetables and fruits is $0.093/lb.[7]

3.2 Baseline results

The estimated annual benefit of HAW-FLYPM is approximately $9.3 million with Hawaii's consumers receiving approximately $3.3 million and Hawaii's producers receiving approximately $6.1 million (see Table 2). The benefit generated from tomato is the greatest, followed by watermelon, cucumber, and green pepper. The benefit from these four crops comprises about 85% of the total estimated benefit. The implementation of HAW-FLYPM would make Hawaii's production of bitter melon, cucumber, pumpkin, tomato, and watermelon sufficient to meet the entire local demand and Hawaii will become self-sufficient in these products. Subsequently, Hawaii's consumers of these five products would be better off due to decreased price resulting from the additional supply. On the other hand, Hawaii's consumers of green pepper, eggplant, and Italian squash would not benefit from this program because the increased local production of these three crops would not be sufficient to replace completely the imports. In contrast, Hawaii's producers of all eight products are expected to be better off from this project.

3.3 The effects of transport cost

Without considering transport cost, Hawaii's increased production is assumed first to replace the imported crops from the U.S. mainland market. After all the imports are replaced, the extra local production is then assumed to be exported to the U.S.

[7] The rate is estimated based on a 40 FT, 8'6", refrigerated container, holding 40,000 lb cargo, shipping between the Hilo port in the state of Hawaii and the Long Beach port in the state of California. The rate includes fuel surcharge, terminal charge and other costs.

mainland market. As we pointed out in Sect. 2, there is no change in the Hawaii market price during this process. The estimated annual benefit in this instance is approximately $11.1 million entirely in producer surplus. As compared to the situation where transport cost is considered, the benefit is overestimated by approximately 20%. Therefore, ignoring transport cost would significantly overestimate the benefit from HAW-FLYPM and bias its distribution entirely toward Hawaii's producers.

3.4 Sensitivity analysis

Sensitivity analysis is conducted to test the robustness of our estimates owing to the imprecision of own price elasticity of demand, supply elasticity, transport cost, and the degree of damage suppression. The results indicate that own price elasticity of demand would hardly influence our estimates. For instance, increasing the demand elasticity by 20% for each crop would only enhance the annual benefit by roughly 1%. Conversely, estimation of the benefit is sensitive to the supply elasticity. For instance, reducing the supply elasticity from 0.8 to 0.6 (declined by 25%) would enhance the annual benefit by approximately 35%. The potential benefit declines with the supply elasticity. Since the supply elasticity assumed in this study is rather high (0.8), it is more likely that the annual benefit of HAW-FLYPM is underestimated in this exercise.

The analysis in the preceding section indicates that the annual benefit would be overestimated by approximately 20% when transport cost is completely ignored (i.e., reduced transport cost by 100%). Changes of transport cost in a reasonable range (i.e., 5–20%), however, would not seriously influence our estimation.

The size of the supply shift (or the degree of damage suppression), of course, is the key parameter in our estimation. If the increase in production were reduced from 40 to 30%, the related annual benefit would decrease by approximately 23%. If HAW-FLYPM enhances production by 50%, the resulting annual benefit would be approximately 22% more than that from a 40% increase in production. With a 50% increase in production, the total annual benefit would be overestimated by approximately 28% if transport cost were ignored. Overestimation in this instance, therefore, is severer as compared to the baseline scenario (overestimated by 20%). In addition, Hawaii's producers of bitter melon would now be able to export their crop to the U.S. mainland market compared to autarky in the baseline scenario. Hence, when area-wide pest management causes substantial damage suppression, neglecting the effects of transport cost in estimation could be *dangerously* misleading.

3.5 Benefit-cost analysis

The initial program cost of HAW-FLYPM is estimated as $12 million, excluding costs borne by Hawaii's producers and future public costs to maintain the program (HAW-FLYPM Newsletter 2007). Together with the potential benefit estimated previously, we can readily conduct a cost-benefit analysis. The present values of the annual benefit flows are approximately $42.4 million and $44.8 million, respectively, for discount rates of 2% and 5%, assuming a 5-year planning horizon (see Table 3). The present values of the annual benefit flows for a longer 10-year planning horizon

Table 3 Present value of the potential benefits ($1,000)

Duration	5 years		10 years	
Discount rate	2%	5%	2%	5%
Present value	44,827	42,386	85,428	75,597

The initial program cost is estimated as $12 millions

are approximately $75.6 million and $85.4 million, respectively, for discount rates of 2 and 5% (see Table 3). Although incomplete, if HAW-FLYPM could successfully suppress fruit flies at the current level, or even lower levels, the potential benefit arising from HAW-FLYPM would very likely offset its $12 million or higher program cost. The implementation of HAW-FLYPM, therefore, would improve the welfare status of Hawaii's producers and consumers of fruit-fly-susceptible crops.

4 Conclusion

Decision on the adoption of area-wide pest management is contingent on its potential economic consequences. Implementation of area-wide pest management over a large geographic area can considerably affect the productions of susceptible crops. For a small, open economy, it may even alter its trade status. In this instance, transport cost is a vital factor influencing trade pattern and price and thus bears important welfare implications to the adoption of area-wide pest management. In this paper, we extended Alston et al.'s analytical framework by incorporating transport cost. The extended framework then is applied to the Hawaii Fruit-Fly Integrated Area-wide Pest Management Program. The results indicate that excluding transport cost could overestimate the annual benefit from HAW-FLYPM by 20% if the project enhances the original production by 40% and that the overestimation would be severer as the degree of damage suppression increases. More importantly, the benefit will be distributed entirely to Hawaii's producers if transport cost were ignored. Transport cost, indeed, bears significant welfare implications regarding the size and the distribution of the potential benefit from area-wide pest management. It is paramount for policy-makers and analysts to take into account the effects of transport cost in estimating the welfare consequences associated with the adoption of area-wide pest management, especially when such adoption causes significant changes in production.

While the welfare consequences of adoption of area-wide pest management are currently analyzed in the intermediate and long-term perspective, one could incorporate the dynamic aspect of adoption of area-wide pest management or a production-enhancing technology in general into the framework. For example, the replacement of imported products by the domestic products could be a gradual process, and the yearly benefit will increase as the replacement rate increases. It is also desirable to investigate the possible structural change in production and supply when the growers adopt a production-enhancing technology. For example, the growers might further adjust their production resources and scale in response to the increased productivity. Other factors such as the response of the competitors (i.e., the distant suppliers), trading contract, and trade barriers, could also affect the resulting benefits and are worthy of further investigation.

The extended analytical framework proposed in this paper is applicable to assess the welfare consequences of a supply shock caused by other agricultural innovations besides pest management occurring in a small, open economy. The economic implications of excluding transport cost in fact go well beyond its impacts on the size and distribution of the potential benefit. For instance, transport cost can also affect trade volume and mix of traded products. Therefore, whenever trade is involved decision-makers ought to be cautious about the potential impacts of transport cost on the welfare consequences of the adoption of an agricultural innovation.

Acknowledgments We would like to thank Stuart Nakamoto, Donna J. Lee, and two anonymous reviewers of ARSC, for their constructive comments and suggestions. We are especially indebted to Henry Kinnucan for his suggestion in using expressions (5)–(9) to represent the price and quantity effects. The study was supported in part by a grant from the U.S. Department of Agriculture under Cooperative Agreement # 58-5320-1-492.

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