The Mediterranean Fruit Fly: Efficient Dynamic and Static Phytosanitary Measures, Information Values, and Current Policy

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Abstract

A bioeconomic model is used to examine efficient dynamic and static phytosanitary policies (cold treatment periods) designed to maximize the annual present value of net monthly U.S. welfare associated with trade in commodities that serve as hosts for the Mediterranean fruit fly (medfly). Accounting for the presence of the current U.S. medfly detection and control program, efficient dynamic and static policies require less cold treatment and increase U.S. welfare 9% and 3%, respectively, relative to the current minimum 14-day treatment period. The potential value of adjusting treatment periods regularly using available information on medfly pressure abroad is shown to be nontrivial.

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Twenty of the twenty-one outbreaks of the Mediterranean fruit fly (medfly) that have occurred in the continental United States since 1929 have occurred in Florida and California. To protect producers of fruits and vegetables in these states, the U.S. Department of Agriculture (USDA) together with California's and Florida's agriculture departments adopted Preventative Release Programs (PRPs), which have reduced the severity, duration, and frequency of medfly outbreaks considerably.[1] USDA also regulates the importation of medfly host commodities from foreign countries, in which the medfly is known to exist, to reduce the rate of new introductions. Among the approved and commonly applied phytosanitary measures is cold treatment, under which host commodities imported for fresh consumption are refrigerated in accordance with mandatory period-temperature specifications.

Because live medflies were confirmed in separate shipments of clementines from Spain, during November and December of 2001, USDA amended regulations governing the importation of clementines from Spain (USDA 2002a) and the cold treatment of host commodities from all regions with the medfly (USDA 2002b). One of the reasons cold treatment periods were amended was because research conducted after the detections suggested the previous treatment periods may not achieve a 3.2e-5 post-treatment survival rate (probit 9), which is USDA's objective for the medfly.

Livingston (2006) examines cold treatment periods that maximize net U.S. welfare under USDA's current medfly detection and control program using a bioeconomic

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[1] Instead of the previous practice of releasing sterile female and male adult medflies simultaneously, only sterile males are released, increasing the probability that wild female medflies mate with sterile males. The means of governmental costs of California eradication campaigns are \$84.91 (± \$66.04) and \$2.88 (± \$3.20) million before and after adoption of the PRPs, respectively; and the means of campaign lengths are 1.58 (± 0.65) and 0.66 (± 0.32) years before and after adoption. The mean governmental cost of eradicating the medfly in an average 0.69 (± 0.31) years is \$16.26 (± \$13.65) million in Florida before adoption, and there have been no eradication campaigns in Florida since adoption. All pecuniary values are reported in 2005 US\$ (U.S. Department of Commerce 2005).

optimization model and shows that the efficient level of quarantine security increases with medfly pressure abroad. Efficient static treatment periods are lower than the current minimum 14-day treatment period and, as a result, efficient post-treatment survival rates are much higher than the probit 9 level. In addition, under the base model, adoption of the efficient static policy increases annual U.S. and quarantine-country (QC) net welfare by 3.0% and 1.6%, respectively.

The previous model simulates population dynamics, detection, control, yield loss, and control costs in the QCs; representative QC producer profit maximization; the impact of treatment periods on QC producer behavior and medfly survival; the rejection of U.S. imports infested with live medflies at U.S. ports; wild and sterile medfly population dynamics in the United States under the PRPs; and partial equilibrium welfare impacts. However, the previous model does not allow cold treatment periods to be updated during the year; rather, efficient treatment periods (static policies) remain fixed throughout. Because fruit cutting and inspection data can be used to update information on medfly pressure abroad, treatment periods can be updated during the year.

The analysis is therefore extended to incorporate monthly information flows on medfly pressure in the QCs using a dynamic programming version of the previous model. The objectives are to examine dynamic cold-treatment policy functions, to estimate the value of updating treatment periods at monthly intervals, and to compare U.S. and QC net welfare under efficient dynamic and static policies and the current 14-day treatment period. Under the base model, efficient dynamic treatment policies increase the annual present value of net U.S. welfare by 6% and 9% relative to the efficient static policy and the 14-day treatment period, respectively, suggesting a potential value for using inspection data to update treatment periods regularly. The representative QC producer is slightly better off under the efficient static treatment period, which improves export profitability slightly over 1% relative to the 14-day treatment period.

The Model

Because the previous model is described elsewhere (Livingston 2006), it is only sketched in this section. There are two import markets, the United States and the rest-of-the-world (ROW), and three suppliers: the QCs, the United States, and ROW. Observations on imports, exports, and real prices of an aggregate medfly host commodity for 1994-2003 are used to estimate a system of linear inverse demand and supply equations for the United States and ROW ($R^2 = 0.63$, $\sigma = 1.57$, $df = 33$), which are used to simulate the welfare impacts of cold treatment policies.[2, 3]

Medfly populations are simulated using a Leslie (1945) matrix with age-specific survival and fecundity rates (Krainacker, Carey, and Vargas 1987). Medfly detections are simulated using empirical results reported by Cunningham and Couey (1986) who estimated a relationship between the proportion of medflies captured in a centrally-located trap and the distance away from the trap sterile medflies were intentionally released in a Hawaiian macadamia orchard ($R^2 = 0.99$).

At the end of each week, a representative QC producer sprays an insecticide if the mean of the simulated daily captures exceeds 2.5 (USDA 2002a). Data on spray

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[2] The aggregate host commodity includes apple, apricot, avocado, bell pepper, blueberry and cranberry, cherry, citron, eggplant, fig, kiwi, grape, grapefruit, lemon, mandarin, mango and guava, orange, papaya, peach and nectarine, pear and quince, pineapple, plum and prune, and tomato. Data on QC exports of these commodities (from a total of 65 countries) during 1994-2003 (U.N Trade Statistics 2004) was used to estimate a fixed annual export level for 2005, roughly 9.5 million metric tons. This figure divided by 12 is the total available QC export level during each month.

[3] U.S. import price is a function of a constant and the import level from all suppliers; and the supply price is a function of the import level and a dummy variable, equal to zero during 1994-2001, the period before the regulations were amended, and one during 2002-2003. Coefficient estimates are significant ($p < 0.05$), except for the slope coefficient in the U.S. import demand curve, and have the appropriate signs.

mortality and days after malathion application (Keiser 1989) were used to estimate a mapping relating simulated pesticide sprays to mortality ($R^2 = 0.93$, $\sigma = 0.40$, $df = 3$). Because data were not available to estimate a relationship between infested fruit and yield loss, monthly yield loss is given by the mean monthly fraction of fruit infested with eggs and larvae (infestation rate), assuming medflies are uniformly, spatially distributed.

Medfly eggs and larvae introduced into the United States during a given month, m, are based on the mean infestation rate, a parameter specifying the average number of eggs and larvae per infested fruit (slightly over three), U.S. imports from the QCs during m, and the cold treatment survival rate, the latter of which depends primarily on the length of the treatment period. A logit model was estimated using observations on egg and first-, second-, and third-instar survivors, treated eggs and larvae, and treatment periods and temperatures (Back and Pemberton 1916, Powell 2003). All coefficient estimates are significant ($p <$ 1e-4), except for the intercept in the survival equation for eggs and first instars ($p = 0.68$).

U.S. imports of the host commodity from the QCs arrive in break-bulk shipments, within which cold treatment is applied (USDA 2002a). In accordance with the regulations, a random sample of fruit (slightly over 700) is selected from each shipment, cut, and inspected at the port. If a live egg or larvae is detected, the individual compartment from which the infested fruit is sampled is diverted to ROW at no additional cost. Because this is sampling without replacement, the fraction of imports diverted is given by the hypergeometric probability that at least one live egg or larvae is detected in the average break-bulk shipment.

The QC producer pays for cold treatment and shipping expenses for host commodities exported to the United States using cost estimates reported by USDA (2002c). Detection cost per metric ton are given by the marginal production cost of purchasing, maintaining, and servicing a medfly detection trap in Florida for six weeks with additional adjustments (Carpenter 2004; MAPA 1999, 2001; USDA and FDACS 2002). Spray cost per metric ton is based on California costs (Siebert 1999) and average yield in Spanish clementine orchards (MAPA 1999, 2001).

Marginal production cost is based on production costs for apples, avocados, grapes, grapefruit, guava, nectarines, oranges, papaya, peaches, pears, plums, sweet cherries, tangelos, tangerines, and tomatoes in California (U.C. Davis, various years). Using domestic fresh production during 1994-2003 (USDA 2004b) as weights, mean U.S. real production cost is $681.24 per metric ton. Using QC and ROW export levels during the same period (United Nations 2004) as weights, mean real production costs for the QCs and ROW are $598.02 and $562.39 per metric ton, respectively.

Of total annual U.S. imports of apples, avocados, berries, citrus, grapes, mangoes, peaches, pears, plums, other fruits and tomatoes from all sources during 1989-2005, 16.4, 20.7, 20.3, 13.1, 4.9, 2.7, 1.7, 1.3, 1.7, 2.6, 4.5 and 10.1% was imported, on average, during the months January through December, respectively (USDA 2006). In the model simulations, total annual U.S. imports from all sources is fixed for 2005, and the monthly fractions of this total imported from all sources is fixed at the above percentages to be consistent with historical monthly trade flows.

For larvae to escape from imported hosts, pupate, and emerge as adults capable of founding new populations fruits must be discarded in a manner and in areas suitable for their development. The number of eggs and larvae of each age class surviving cold treatment are therefore multiplied by 1.0e-3, which is the fraction of daily U.S. per capita fresh fruit consumption composted during 2001 (U.S. Census Bureau 2000, USDA 2004c, U.S. Environmental Protection Agency 2003). Assuming imports of medfly host commodities are distributed uniformly to the 48 continental states based, for example, on population levels, only 18% of total annual U.S. imports would enter California or Florida, where recall 20 out of 21 of the medfly outbreaks have occurred. Therefore, it is very likely that multiplying the number of medflies that survive cold treatment each month by 1.0e-3 provides an upwardly biased estimate of the number subsequently introduced into the United States.

At the beginning of each week the density of introduced, wild medflies and the number of adults captured per trap per square mile are calculated for California's and Florida's PRP areas as if they were one aggregate detection and release area. Weekly monitoring and PRP release costs and weekly PRP releases of sterile male medflies are also simulated. The weekly cost per trap is the product of the number of traps and the weekly cost of maintaining and servicing one trap (Carpenter 2004, USDA and FDACS 2002), and the weekly cost of releasing sterile medflies is the product of the weekly number released and the cost per fly (Burnett 2005).

If the number of *wild* medflies captured at the beginning of the week exceeds one in a given area, an eradication campaign is simulated according to current protocol (USDA 2003a): the number of detection traps per square mile is increased; the number of sterile medflies released weekly is increased; and a bait spray is applied. The size of the area in which this occurs and therefore the cost are based on eradication campaigns conducted since adoption of the PRPs.

The mean governmental cost and duration of eradication efforts since adoption of the PRPs are \$2.88 million and 4.6 weeks; therefore, U.S. producers are assumed to lose \$621,669 each week an eradication campaign is in effect. In addition, during an eradication campaign, monthly U.S. exports to ROW are reduced by a proportionate yield loss given by the mean monthly infestation rate. An 11-day shipment period is assumed for the U.S. exporter; therefore, \$35.31 per metric ton is deducted from total revenue, as are production costs of \$681.24 per metric ton. ROW producers export 2.245 million and 13.124 million metric tons to the United States and ROW, which are estimates for 2005 based on total imports for these markets. Revenues, however, fluctuate with QC producer exports to both markets. Production costs (\$562.39 per metric ton) are assessed, but shipping costs are not under the assumption that ROW producers who export to the United States and ROW are geographically close to these markets.

Daily population dynamics for sterile and introduced, wild medflies are simulated in the U.S. PRP area. Population dynamics for sterile and wild medflies are simulated using the Leslie (1945) matrix described earlier, with the fecundity parameters reduced to zero for the former and reduced by the wild-male fraction of total males (sterile plus wild) in the area for the latter.

At the beginning of each month, the representative QC producer chooses the fraction of available exports to ship to the United States, $x_t\left(c_t, s_t^1\right)$, with the remainder shipped to ROW, to maximize monthly profit; where $x_t\left(c_t, s_t^1\right)$ depends on the number of medflies in the QCs at the beginning of the month, s_t^1, and the length of the cold treatment period, $c_t \equiv c_t\left(s_t^1, s_t^2\right)$, which is also a function of the number of wild medflies in the United States at the beginning of the month, s_t^2. A U.S. regulator is assumed to know s_t^1, s_t^2, $x_t\left(c_t, s_t^1\right)$, and s_{t+1}^1 and s_{t+1}^2 via the bioeconomic model, $\left[s_{t+1}^1, s_{t+1}^2\right] = b\left\{x_t\left(c_t, s_t^1\right), s_t^2\right\}$.

At the beginning of each month the regulator chooses the cold treatment period to maximize the discounted sum of U.S. net welfare over 12 months. The planner's decision rules are examined using the Bellman equation

$$v_t\left(s_t\right) = \max\ w_t\left(x_t\left(c_t, s_t\right), s_t\right) + \rho v_{t+1}\left(b\left\{x_t\left(c_t, s_t\right), s_t\right\}\right); \quad (1)$$

where $v_t\left(s_t\right)$ is the maximum present value of net U.S. welfare from period *t* to the final period; $w_t\left(x_t, s_t\right)$ is net U.S. welfare during *t*; *ρ* is a fixed discount rate; and $s_t = \left[s_t^1, s_t^2\right]$. During any *t*, maximization of Bellman equation (1) is with respect to policy function, c_t, which depends on both state variables.

Medfly populations are not valued beyond the final period, *T* = 12 months; therefore, Bellman equation (1) can be solved recursively starting in *T*, where the value function is known, $v_T\left(s_T\right) = w_T\left(x_T, s_T\right)$. The state space consists of 50 equally-spaced nodes each for s_t^1, between 3,768,322 and 53,463,740, and s_t^2, between 0 and 1000. At each state, s_t, and treatment period, c_t, the representative producer chooses the fraction of a fixed level of exports to ship to the United States to maximize profit with the remainder shipped to ROW. Given the QC producer's decision rule, the treatment period that maximizes U.S. welfare in the final month is found for each state. Coefficients of a cubic spline are then found that equate the value of the spline to the value function at the 2500 state values; the same is done for the cold treatment policy function for later evaluation. With these coefficients in hand, period *T*-1's value function is found using Bellman equation (1), using the cubic spline to approximate period *T*'s value function. This process continues until the first period's value and policy functions are found.

The domains for both state variables are based on maximum likelihood estimates of initial infestation rates in the QCs and simulated population levels recorded during the analysis of efficient static cold treatment periods. The maximum likelihood estimates were based on the biological model; the assumption that infestation rates are characterized well using a beta distribution; and fruit cutting, inspection, and carton rejection data collected by USDA as part of the Spanish pre-clearance program for clementines exported to the United States during the 2002-2003, 2003-2004, and 2004-2005 marketing years (USDA 2005). Because the results were found not to depend on the initial medfly population level in the United States, and because it is widely assumed that medflies are not established, the results are presented for different starting values for the initial QC medfly population.

Results

The time paths of U.S. net welfare and U.S. imports from all sources follow the same pattern, because consumer surplus increases with imports due to lower prices and higher imports. U.S. net welfare does not vary appreciably with the initial QC medfly population at the beginning of the year, $s_1^1,$ because medfly populations are controlled according to a fixed population threshold rule and, for the plausible range of initial values examined, populations are maintained at similar levels within a few months (Figure 1). In addition, efficient treatment periods increase with monthly QC medfly populations and, as a result, the time path of U.S. net welfare is very regular.

The fraction of available QC monthly exports shipped to the United States (Figure 2), the monthly U.S. import price, and QC producer profit follow the same pattern, which is opposite that of U.S. net welfare. There is no appreciable variation in the export fraction with the initial QC medfly population level, s_1^1. QC producer welfare follows the same path as the fraction of available exports shipped to the United States.

The time paths of efficient treatment periods; however, depend relatively more on the time paths of QC medfly populations (Figure 3). This can be observed most clearly by examining the efficient treatment period during the first month, which increases with the initial QC medfly population level, s_1^1. Because the population threshold rule observed by the representative QC producer forces subsequent populations to a narrow range during March through September, efficient treatment periods hover around six days irrespective of the initial starting value for s_1^1.

Increases in medfly populations, however, do occur toward the end of the year, which sometimes appear to exceed a threshold level leading to sharp increases in the efficient treatment periods for those months. In particular, the spikes in the efficient treatment periods appear more than warranted by the spikes in QC medfly populations when compared to the beginning of the year. This occurs because the QC producer ships more to the United States during the end of the year and because U.S. medfly populations, although very small in comparison, peak toward the end of the year.

The means of the efficient monthly treatment periods increase with the initial QC medfly population level. They are, respectively, 5.8 ± 1.3 days, 6.3 ± 0.4 days, and 6.9 ± 1.6 days for intial populations 3.8, 28.6, and 41.0 million. Note, interestingly, that the variability in the efficient monthly treatment periods does not increase monotonically with the initial QC medfly population level.

Over this range of initial QC medfly populations, the present value of annual U.S. net welfare is 6 and 9% higher, respectively, than the present value of annual U.S. net welfare received under the efficient static treatment period, which averaged 8 days, and under the current minimum treatment period of 14 days. This suggests a potential nontrivial value for updating treatment periods during the year.

Because profit received by the representative QC producer is maximized under a nine-day treatment period, on average, the QC producer is slightly better off under the efficient static treatment period relative to the efficent dynamic treatment period. However, the present value of QC producer profit is one percent higher under the efficient dynamic treatment periods relative to the current 14-day minimum treatment period.

Conclusions

A bioeconomic model is used to examine efficient dynamic and static phytosanitary policies (cold treatment periods) designed to maximize the annual present value of net monthly U.S. welfare associated with trade in commodities that serve as hosts for the

Mediterranean fruit fly (medfly). Accounting for the presence of the current U.S. medfly detection and control program, efficient dynamic and static policies require less cold treatment and increase U.S. welfare 9 and 3%, respectively, relative to the current minimum 14-day treatment period. The potential value of adjusting treatment periods regularly using available information on medfly pressure abroad is shown to be nontrivial.

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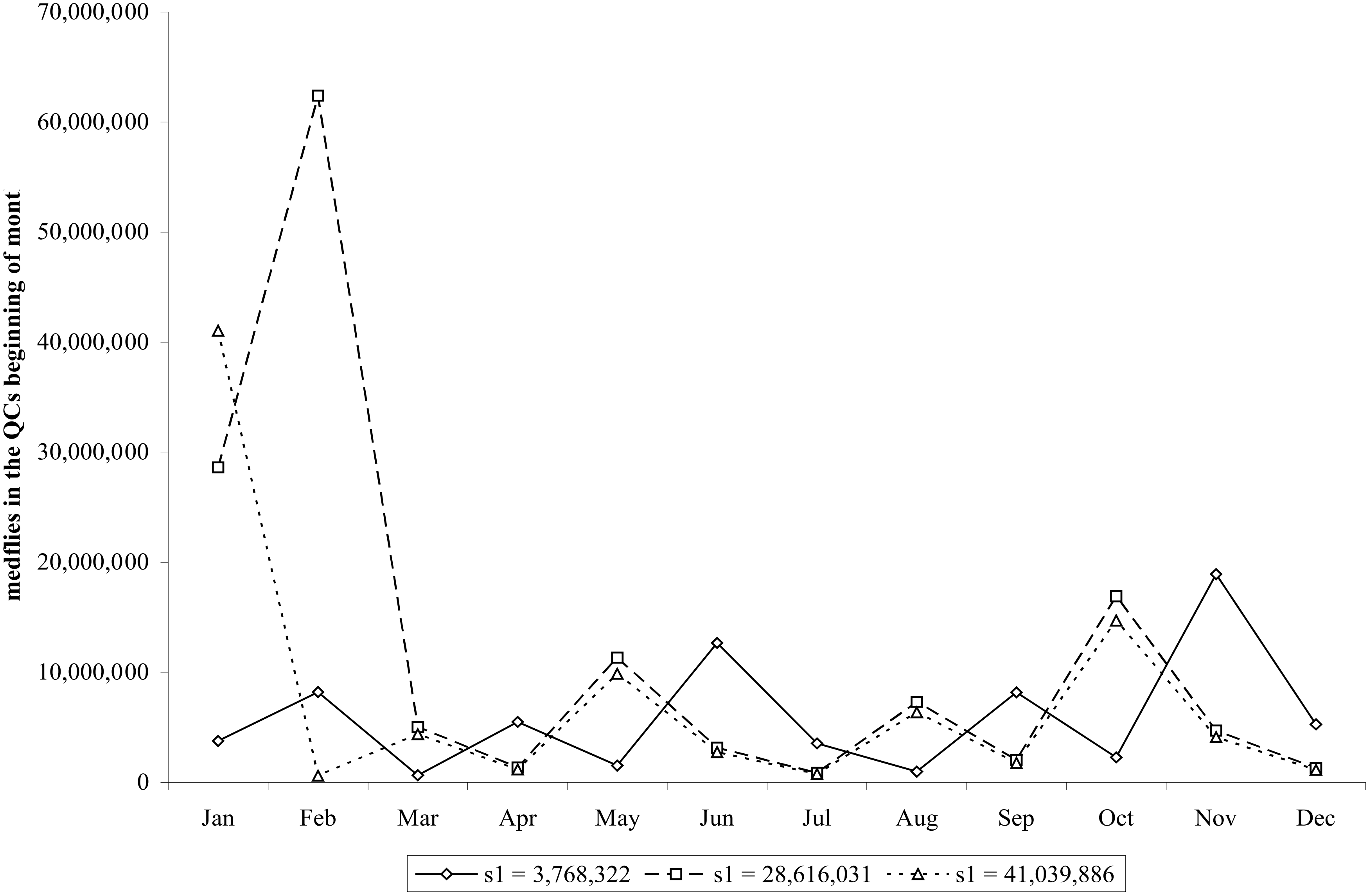

Figure 1. QC medfly populations at the beginning of the month for different starting values, s_1^1.

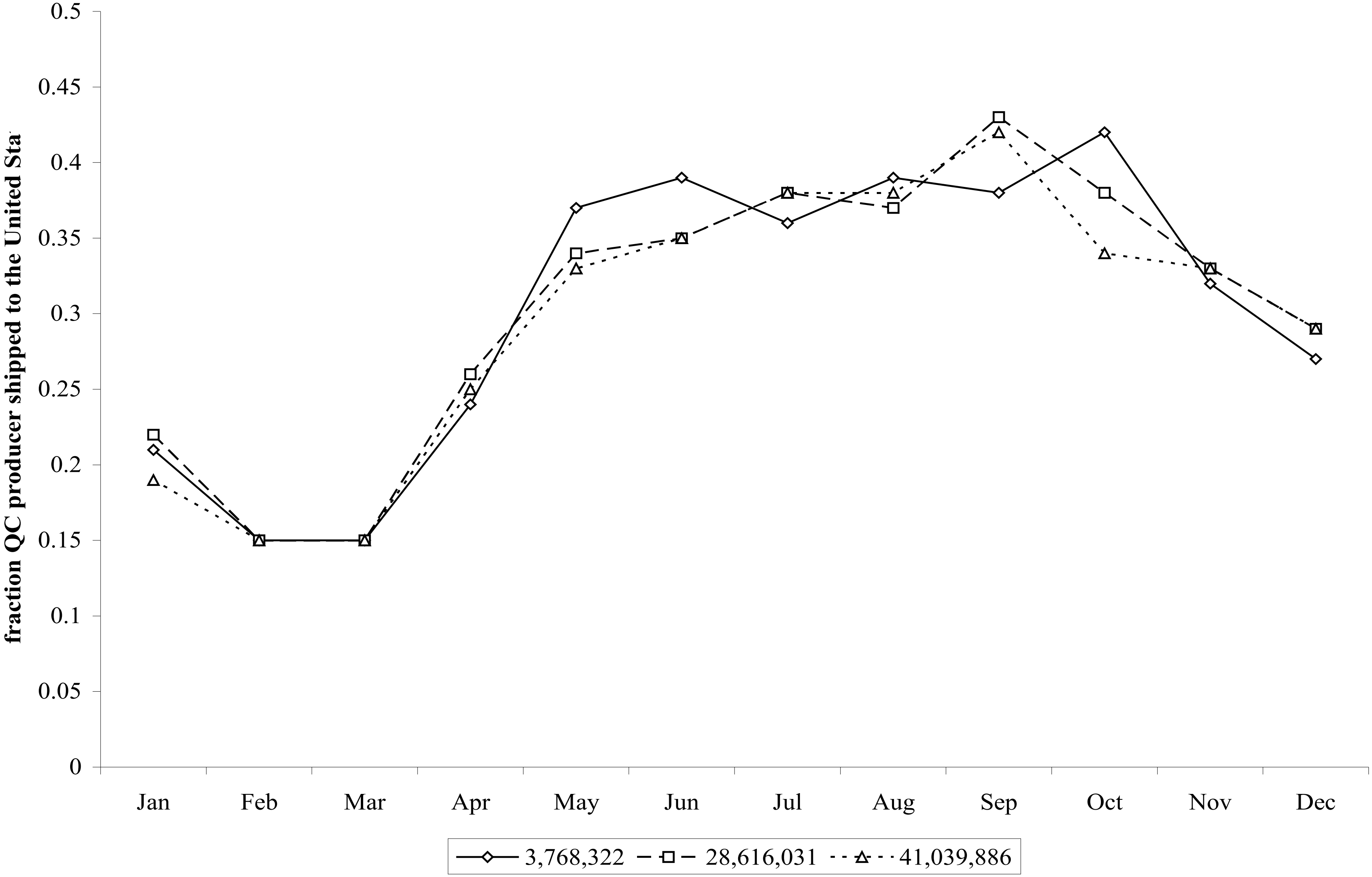

Figure 2. Profit maximizing QC-to-U.S. export fractions for different initial QC medfly populations, s_1^1.

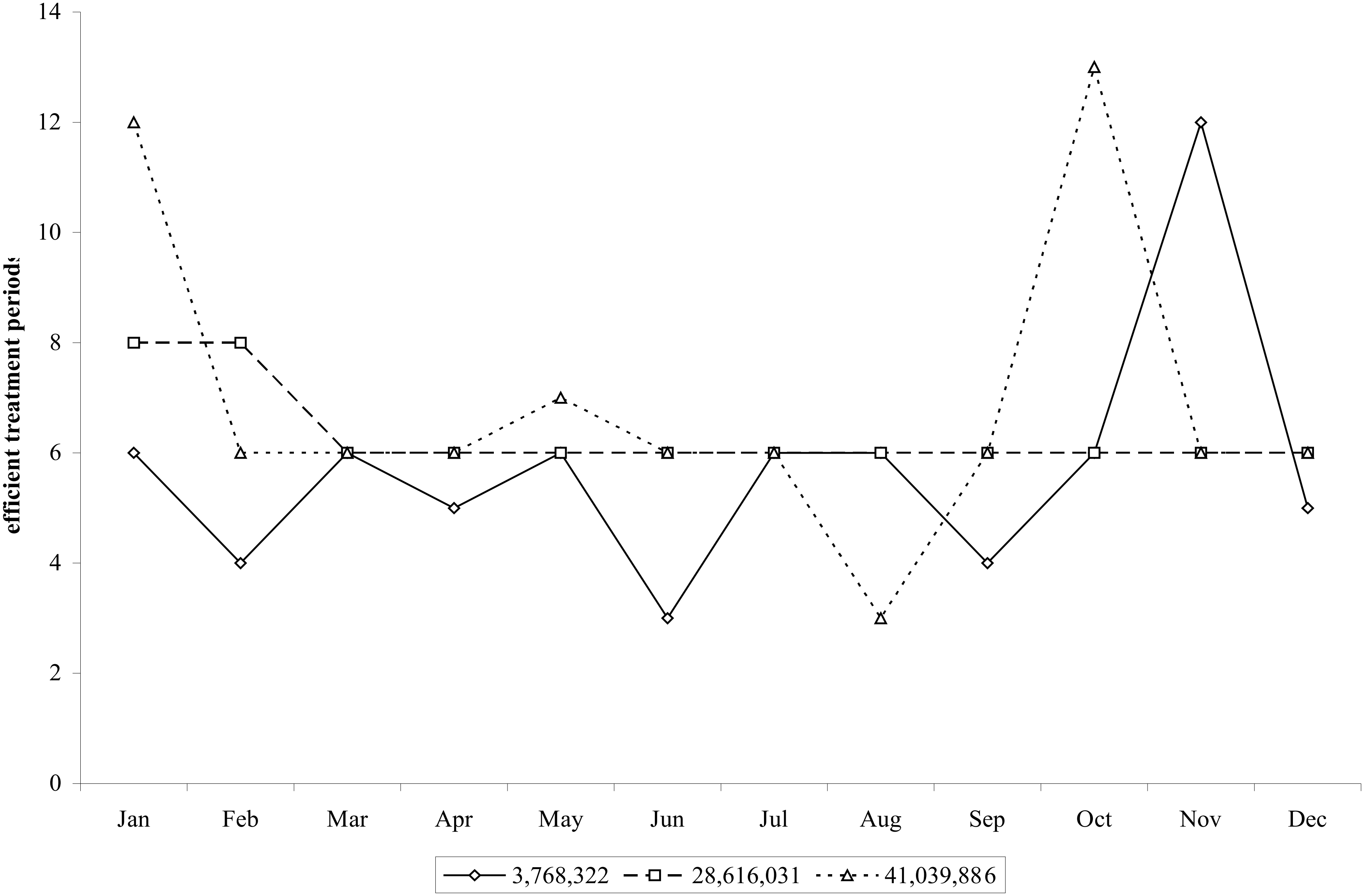

Figure 3. Efficient cold treatment periods for different initial QC medfly populations, s_1^1.