THE ECONOMICS OF MIXED CARGO AND CRUISE SHIP TRAFFIC IN A PORT

By Thomas W. Wood*

Two conditions common in developing countries are dependence on imports for a substantial portion of domestic consumption, and the existence of a tourism industry. When both imports and tourism use water transport, competition can develop between cargo and cruise ships at limited port facilities.[1] A large and growing literature[2] deals with competition among cargo ships and its economic effects; a gap exists in the theory and practice of describing and predicting the effects of competition between the two classes of traffic.

The aims of this paper are therefore: (1) to provide a theoretical basis for comparing the economic gains due to efficiencies in cruise and cargo traffic throughput; (2) to set forth a simple technique for modelling the competition between cruise and cargo traffic under a commonly used priority rule; and (3) to use data from a case study on Antigua, West Indies, to illustrate how priority policies may appropriately change with changes in traffic mix.

Achievement of the first aim makes possible a rational framework for allocating port resources between the two categories of traffic. The formulae developed in achieving (2) are simple enough to allow port planners and engineers to utilise them in designing new port facilities and recommending management policies for the best use of existing port facilities.

A WELFARE THEORY OF PORT GAINS

Efficiency of Cargo Throughput

A simple welfare economics model is adequate to describe the most important features of gains from throughput efficiencies for both cargo and cruise ships at a port. A two-good, one-consumer model captures the important differences in how benefits are generated. Figure 1 illustrates the case where the consumer is in equilibrium on indifference frontier U_0 under a linear budget constraint (constant prices) for an imported good and a domestic good. A portion of the price for the imported good is made up of transport cost, which includes cost of throughput

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[1] The competition is not governed by prices; this accounts for much of the special nature of this problem.

[2] The best recent summary is Bennathan and Walters (1979).

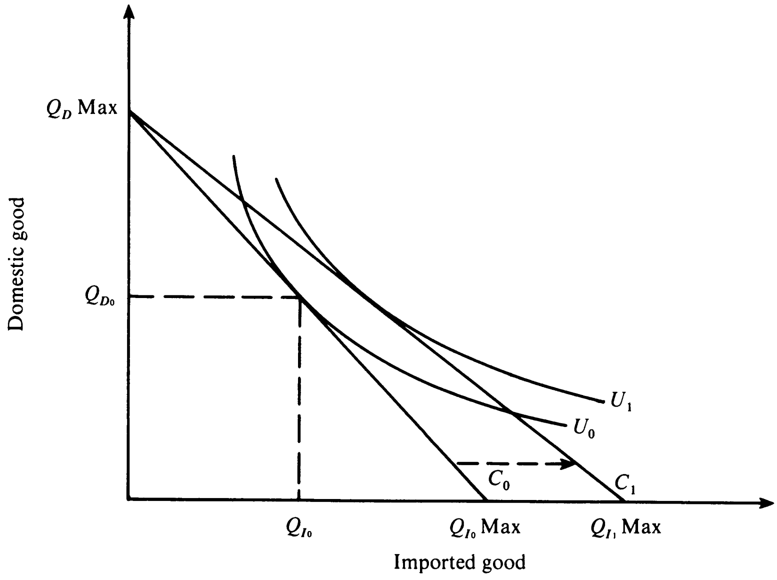

FIGURE 1

Welfare Gains from Port Improvement—Cargo Only

at the port. The case in which throughput becomes more efficient can be represented by an outward shift of the budget frontier (rotating around the maximum consumption of the domestic good). This is just a decrease in the price of the imported good, and leads to an unambiguous welfare gain. Conversely, increases in the price of the imported good (if we once again maintain the same "money price" for the domestic good) lead to an unambiguous welfare loss.

The economic theory which describes the welfare gains and losses due to price changes of an imported good is almost trivial, but the practical port planning techniques used to estimate gains and losses in prices of imports (and exports) due to port improvements are much more complex. It suffices here to say that much of the throughput cost of imports at the port is comprised of ships' waiting time. The costs are assumed (in a competitive shipping market) to be ultimately passed on to consumers. This basis of measuring port throughput efficiency for cargo ships seems to be accepted by all theoretical economists, and also by most of the practitioners of port design and planning.

Cruise Ship Benefits

Cruise ship tourism is widespread, and widely acknowledged to create benefits for the recipient country. The nature of these benefits, and in particular how they may be made commensurate with benefits from throughput efficiency for cargo, has not been thoroughly explored. That port authorities and governments recognise cruise traffic as beneficial is evidenced by the fact that in nearly all ports cruise ships are granted priority of one sort or another over cargo trade. This priority may take the form of preferential scheduling, or it can mean that service to cargo vessels is interrupted while cruise ships are served.[3] It is in the nature of cruise trade that cruise ships will not form queues, but typically will steam to another port when faced with even slight delays; this reinforces the universality of the practice.

A naive conception holds that the benefits generated by cruise traffic are approximated by the expenditures of passengers in a recipient country. Simple economic logic suggests that the cost of the output purchased by cruise passengers must be taken into account to arrive at net benefit. In macroeconomic terms, the value added in products consumed by cruise ship tourists represents a clear income gain for the host country. Since this income gain is exogenous, a multiplier should be applied to arrive at a final income gain.

In the framework of the simple two-good, one-consumer model, this increase in national income is represented by a parallel outward shift in the budget constraint; the outward shift would, *ceteris paribus*, result in an unambiguous welfare gain for the host country.

Figure 2 presents a graphical analysis of the case in which an exogenous increase in the level of cruise traffic (initially) generates a shift in income equal to ΔY. This initial shift in the budget constraint is represented by the move from C_0 to C_1. Given that the priority structure between cruise and cargo traffic is not changed in any way, this exogenous increase in cruise traffic will tend to decrease service levels to cargo traffic at the port. This is especially true where priority structures are of the preemptive type. In these cases increases in cruise traffic generate increases in average waiting times for cargo ships at an increasing rate. The result is a price increase for the imported good, which is graphically represented in Figure 2 by the shift from C_1 to C_2.

This analysis suggests that an exogenous increase in the level of cruise traffic, without any change in the priority policy, *could* result in an overall welfare loss to the host country. Such exogenous changes in the level of cruise traffic are quite common at some ports, particularly in the Caribbean. Changes in political climates at neighbouring (and competing) cruise destinations can often alter the level of cruise traffic dramatically from one season, or even from one month, to the next. Thus, drastic changes in the levels of cruise tourism are not just theoretical events.

Returning to Figure 2, it is possible to derive a condition under which it is certain that a decrease in welfare due to increased prices for imported goods will not be greater than the increase in welfare due to increased national income from spending by cruise tourists . If we write the equation for the original budget constraint C_0 as

$$Q_D = Q_D \,\text{Max} - Q_I[(Q_D \,\text{Max} - Q_D^0)/Q_I^0)]$$

the equation for the constraint C_2 can be written as

$$Q_D = Q_D \,\text{Max} + \Delta Q_D - Q_I[(Q_D \,\text{Max} + \Delta Q - Q_D^0/Q_I^0)]$$

[3] In queuing theory nomenclature the former rule is "nonpreemptive" priority, the latter "preemptive priority".

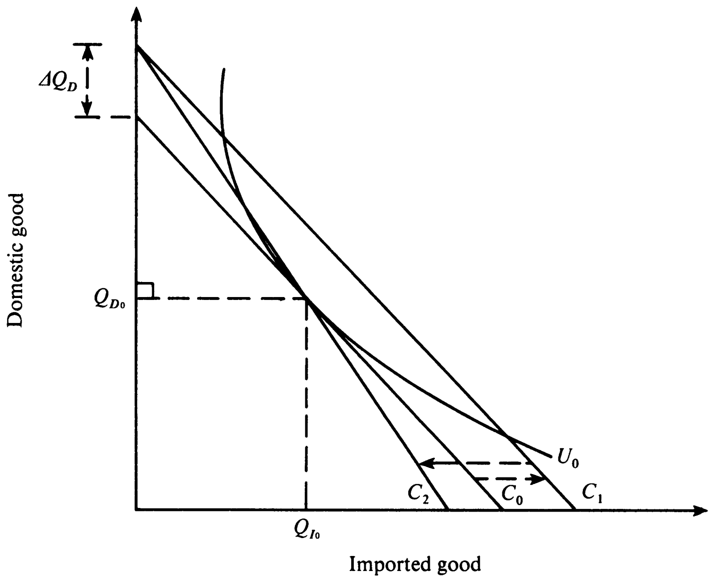

FIGURE 2

Welfare Effects from Changing Congestion Prices Facing Cruise and Cargo Traffic

(The slopes of these two constraints are defined over the range from 0 to Q_1, the original equilibrium position for the imported good.) Since C_2 (for the definition of the condition) is assumed to shift inward only to the extent that it passes through the point Q_{I_0}, Q_{D_0}, it is clear that society will still be on a slightly higher welfare frontier. This inward price shift is given by

$$\Delta P \text{ Max} = \left(\frac{Q_D^0 + \Delta Q_D}{Q_I^0} - \frac{Q_D^0}{Q_I^0}\right).$$

This result reduces to

$$\frac{\Delta Q_D}{Q_I^0}.$$

Conversion to "money prices" gives

$$\left(\frac{\Delta Y/P_D^0}{Y_0/P_I^0}\right).$$

Thus, knowledge of original income, prospective income gains due to increases in cruise traffic, and the original prices of imported and domestic goods provides an approximation of the maximum change in prices of imported goods which is acceptable from the point of view of maintaining welfare.

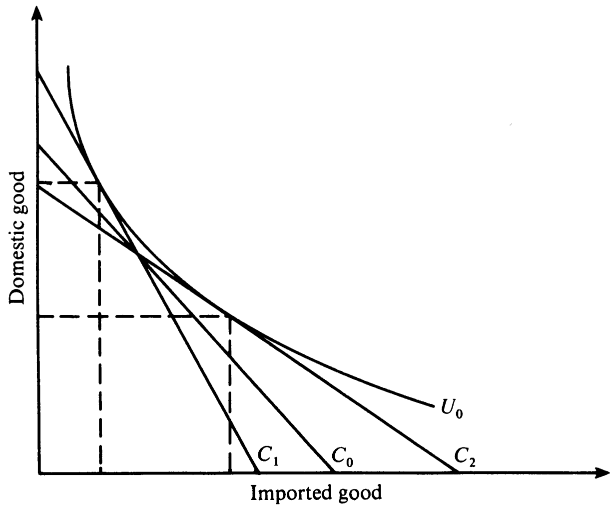

FIGURE 3
Optimal Policy for Port Allocation

Figure 3 illustrates a case in which both traffic of cargo and cruise vessels, and the port facilities available for servicing them, are fixed. The only variable is the priority policy imposed to allocate the limited port resources between the two classes of traffic. The original budget constraint (C_0) represents a "neutral" allocative policy, which would not discriminate in favour of either class of traffic. Under that policy cruise and cargo vessels would have equal chances for the next available berth, and would pay the same charges for use of port resources. Since port charges typically are based in some measure on tons of cargo taken aboard or discharged, the situation would (in practice) require a change to a fee structure in which the use of a port resource (e.g., foot hours of quay wall) was priced directly rather than via throughput of tonnage.

The budget constraint C_1 represents the situation in which priority is given to cruise traffic at the expense of cargo traffic. This results in increased income, but also in an increase in the prices of imported goods due to throughput costs at the port. Budget constraint C_2 represents the opposite situation, in which import prices are decreased through a shift in priorities toward the cargo class, but national money income is less than in the base case, since expenditure by cruise passengers and consequent value added are lower.

It is intuitively clear that it is possible to find the optimum policy, and it turns out to be measurable in terms of the "indirect utility function".[4] This function specifies

[4] See Henderson and Quandt (1958), p. 28, for a review. The exactness of this condition comes at the price of introducing the marginal utility of income into the formula.

income gains necessary to compensate for price changes in any consumer good, and applies directly to the shifts in prices and income in our problem.

Apart from the existence of this optimum, an interesting feature of the welfare representation of mixed traffic is that the nonconvexity of the possibilities frontier in Figure 3 implies that the welfare optimum may not be unique. Since changes in the position and slope of the budget frontier are continuous over the range of income and price increments influenced by port congestion, there could be an infinity of equal welfare solutions.

This example captures the essence of the policy problem confronting a developing country (or its port authority) when faced with mixed cruise and cargo traffic. This problem is: given the port resources, the traffic levels, and the expenditure and price parameters (which define the possible effects on income and price), how best to allocate port resources between the two classes of traffic. The next section presents a simple analytical model of priority queuing which will enable us to explore this question in a sample case.

SIMPLE ANALYTIC MODEL OF CRUISE AND CARGO QUEUING

Waiting Time Calculations

As noted in the introduction, many ports grant priority to cruise vessels over cargo vessels. In many cases this priority is the preemptive form, under which service to a cargo vessel will be interrupted to berth an incoming cruise ship. The properties of the preemptive priority queue have been thoroughly explored.[5]

The parameters of interest here are the average waiting times for each class of service, as functions of the arrival time and service distributions characteristic of each class of service. In the representation standard for queuing theory models, these parameters are:

$$W_{q_1} = \rho_1/\mu_1(1-\rho_1), \qquad \text{or}$$

$$W_{q_1} = (\lambda_1/\mu_1)/\mu_1[1-(\lambda_1/\mu_1)]$$

$$W_{q_2} = \left[\frac{1}{\mu_2(1-\rho_1-\rho_2)}\right]\left[\rho_1+\rho_2+\left(\frac{\rho_1}{1-\rho_1}\cdot\frac{\mu_2}{\mu_1}\right)\right]$$

where W_{q_1} = mean waiting time for Class "1" (the high priority class—cruise ships)
W_{q_2} = mean waiting time for Class "2" (the low priority class—cargo ships)
ρ_1 = cruise ship traffic intensity = λ_1/μ_1
ρ_2 = cargo ship traffic intensity = λ_2/μ_2
μ_1 = cruise ship service rate
μ_2 = cargo ship service rate
λ_1 = cruise ship arrival rate
λ_2 = cargo ship arrival rate

[5] See Gross and Harris (1974) for a discussion of preemptive priorities for Poisson arrivals (which are assumed here).

These formulae are for a single channel model with exponential service and arrival rates. Multiple berths will require more complex models. Also, cases where the cruise trade traffic intensity (ρ_1) is near 1 will give misleading results, since these cases imply a situation where long queues of cruise ships develop.

Costs and Benefits

Since the economic gains to be had from increases in cruise traffic are (at best) a constant linear function of the level of that traffic, a benefit function can be written as:

$$B = K_1 \lambda_1 = K_1^1 . K_1^2 . K_1^3 . K_1^4 . \lambda_1$$

where λ_1 = cruise ship arrival rate
K_1 = a parameter, the product of
K_1^1 = passengers per ship
K_1^2 = expenditure per passenger
K_1^3 = value added to output ratio for goods purchased
K_1^4 = value added in economy per \$ of value added in tourism sector.

The cost of cargo throughput, however, is approximated by the cost of cargo waiting derived earlier. From this, we can predict the costs incurred by cargo vessels as a function of the arrival rate of cruise vessels. Since any priority policy will be effected through changes in the arrival rate of cruise ships (λ_1), we are interested in seeing how these expressions will vary with different levels of cruise traffic.

A cost function in terms of λ_1 is just:

$$C = \lambda_2 W_{q_2} \times c = \lambda_2 W_{q_2}(\lambda_1) \times c$$

C = total cost per unit time

c = cost per vessel per unit time.

Substituting and expanding the ρ terms gives:

$$C = \lambda_2 \left[\frac{1}{\mu_2\left(1 - \frac{\lambda_1}{\mu_1} - \frac{\lambda_2}{\mu_2}\right)} \right] \cdot \left[\frac{\lambda_1}{\mu_1} + \frac{\lambda_2}{\mu_2} + \left(\frac{\mu_2}{\mu_1} . \left\{ \frac{\frac{\lambda_1}{\mu_1}}{1 - \frac{\lambda_1}{\mu_1}} \right\} \right) \right] . c.$$

Maximising the national welfare represented by these benefit and cost formulae requires setting the derivative of this expression equal to the (constant) benefit gained from an incremental increase in cruise traffic. The marginal cost in terms of λ is given by:

$$\partial C / \partial \lambda_1 = \left\{ \left[\frac{\mu_2 \lambda_2 c}{(\mu_1 \mu_2 - \mu_2 \lambda_1 - \mu_1 \lambda_2)^2} \right] . \left[\lambda_1 + \frac{\mu_1}{\mu_2} \lambda_2 + \mu_2 \left(\frac{\lambda_1}{\mu_1 - \lambda_1} \right) \right] \right\} +$$
$$\left\{ \left[1 + \frac{\mu_2(\mu_1 - \lambda_1) + \mu_2 \lambda_1}{(\mu_1 - \lambda_1)^2} \right] . \left[\frac{\lambda_2 c}{(\mu_1 \mu_2 - \mu_2 \lambda_1 - \mu_1 \lambda_2} \right] \right\}$$

The derivation is given in the Appendix. Since the λ_1 parameter is taken as the number of cruise ships per unit of time, marginal benefits are always equal to:

$$\partial B/\partial\lambda_1 = \partial K_1 \lambda_1/\partial\lambda_1 = K_1$$

There are no obvious policy implications to be drawn from the $MC = MR$ condition, but these equations do allow for optimisation of net benefits in terms of control parameter λ_1.[6]

APPLICATION TO PORT OF ST. JOHNS

The port at St. Johns, Antigua, is the only deep water harbour serving an island nation of about 100,000 people. Since both classes of traffic require deep water berthing, the port becomes the focus of cruise and cargo interaction.

This problem has been most severe during the 1979–80 tourist season, when sharply increased calls by cruise ships resulted in increased cargo queuing and in increased need for rescheduling of calls by cargo ships. The anticipated volume of cruise traffic for the 1980–81 season was expected to greatly increase these problems.

The Antiguan economy is heavily dependent on tourism, with about 20% of GDP generated in the tourist sector (Prime, 1980). The import bill is also a very large share of consumption. Thus changes in either levels of tourism or prices of imports can have sizable impacts on national welfare. The parameters required for application of the model given in the previous section are the same as those required for planning of port improvements; they were estimated during the conduct of a study by Stanley Consultants. A summary of these parameters is given in Table 1.

These parameters were used (in the port improvements study) to estimate the gains from low prices (in imports) and increased tourism that would follow expansion of port facilities. Our interest here is in using them to quantify the welfare question posed in Part 1. This is accomplished by allowing λ_1 to vary and observing the resultant marginal benefits and costs. Increases in λ_1 over a range of about 200% give the results in Table 2.[7]

Table 2 illustrates that, although cruise traffic is quite attractive at the (current) margin, increases in cruise traffic quickly drive net benefits down. An increase in traffic by a factor of about 2.3 is sufficient to drive net benefits below zero. Thus, the possibility of overall welfare loss due to exogenous increases in cruise traffic suggested in Part 1 is clearly real for Antigua. Two facts tend to underline the validity of this finding. First, the marginal benefits were held constant in our calculations. In a market where competing cruise destinations vie for bookings, there is good

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[6] While λ_1 is not (in queuing theory terms) a control parameter, it is clear from the nature of cruise ship markets that the level of traffic presented may be controlled.

[7] These calculations are for a 180-day tourist season which peaks in December–February. Since λ_1 and λ_2 are defined in terms of days, the MC and MR are 180 times the values given by the formulae.

TABLE 1
Parameters for Model of Queuing

Parameter	Explanation	Value and Units
λ_1	Cruise ship arrival date	0.306 vessels/day
μ_1	Cruise ship service rate	1.720 vessels/day
λ_2	Cargo ship arrival rate	0.380 vessels/day
μ_2	Cargo ship service rate	1.40 vessels/day
K_1^1	Passengers per ship	600
K_1^2	Expenditure per passenger	U.S.$29.00
K_1^3	Value added/output ratio[a]	0.34 (pure)
K_1^4	Value added multiplier[a]	1.40 (pure)

[a] These values are estimated from data provided by Prime (1980).

TABLE 2
Summary of Marginal Costs and Benefits due to Changes in Cruise Traffic

λ_1	Cruise Traffic	Benefit[a]	Cost[a]	Net Benefit: Per Season	Net Benefit: Per Vessel
		$	$	$	$
0.3	54	1,490,832	438,058	1,052,774	5,848
0.4	72	1,490,832	573,847	916,985	5,094
0.5	90	1,490,832	773,966	716,866	3,983
0.6	108	1,490,832	1,082,678	408,154	2,268
0.7	126	1,490,832	1,587,722	−96,890	−538
0.8	144	1,490,832	2,481,581	−990,749	−5,504
0.9	162	1,490,832	4,250,466	−2,757,639	−15,331
1.0	180	1,490,832	8,412,275	−6,921,443	−38,452

Total cruise traffic per season is $180 \cdot \lambda_1$.
[a] Marginal benefits and costs are for a unit increase in λ_1, which represents 180 vessels per year.

reason to expect that the Nth cruise ship booked will be "less valuable" than the $(N-1)$th. This would lead to declining rather than constant marginal benefits, and a more rapid diminution of net benefits, with increases in cruise traffic.

Second, the analysis of costs using the waiting time approach used a fixed level of cargo traffic, while λ_1 (cruise traffic) varied. In some countries, including Antigua, a substantial fraction of the cargo traffic is due to the needs of cruise passengers. In these cases, a *ceteris paribus* increase in λ_1 is not possible. Waiting time costs which result from this situation will be higher than where cargo traffic is constant.

SUMMARY AND CONCLUSIONS

Both cargo and cruise trade generate important economic benefits to developing countries. Benefits from cargo can be modelled as consumer benefits due to lower prices, and from cruise trade as increases in income due to spending by visitors. The fact that the two types of vessels compete for limited port space implies that increased traffic will create congestion costs. If the increase is in cruise trade, these congestion costs are just a reduction of the consumer benefit from cargo efficiency. The effect on prices can, in theory and practice, overwhelm the beneficial income effect of cruise tourism.

The wisespread policy of granting *automatic* priority to cruise vessels is economically irrational. Traffic levels and port resource mix may warrant this priority in many cases, but its effect should be closely examined in any country which has both types of traffic.

This conclusion may be qualified where imports are not for domestic consumption or for the needs of cruise tourists. For example, where imports are for transshipment or for the demands of tourism by air, an inelastic demand for the ultimate product could diminish or remove totally the welfare costs of increased import prices.

Finally, the notion that cruise ships would not participate in an allocation of port resources by pricing does not justify the continuation of automatic priority. Joint action by several countries in a tourism market to abolish priorities and to ration by pricing could conceivably make them all better off.

APPENDIX

Derivation of Marginal Cost

The total cost function is:

$$C = \lambda_2 c\left[\frac{1}{\mu_2\left(1-\frac{\lambda_1}{\mu_1}-\frac{\lambda_2}{\mu_2}\right)}\right]\cdot\left[\frac{\lambda_1}{\mu_1}+\frac{\lambda_2}{\mu_2}+\left\{\frac{\mu_2}{\mu_1}\cdot\left(\frac{\frac{\lambda_1}{\mu_1}}{1-\frac{\lambda_1}{\mu_1}}\right)\right\}\right]. \qquad \text{(A1)}$$

A preliminary simplification (multiplying μ_2 through denominator of first term and μ_1/μ_1 through rightmost term) gives:

$$\left[\frac{\lambda_2 c}{\mu_2-\frac{\mu_2\lambda_1}{\mu_1}-\lambda_2}\right]\cdot\left[\frac{\lambda_1}{\mu_1}+\frac{\lambda_2}{\mu_2}+\left\{\frac{\mu_2}{\mu_1}\left(\frac{\lambda_1}{\mu_1-\lambda_1}\right)\right\}\right]. \qquad \text{(A2)}$$

Multiplying first term by μ_1/μ_1 and second by $\mu_1\mu_2/\mu_1\mu_2$ gives:

$$\left[\frac{\lambda_2 c}{\mu_1 \mu_2 - \mu_2 \lambda_1 - \mu_1 \lambda_2}\right] \cdot \left[\frac{1}{\mu_2}\right] \cdot \left[\mu_2 \lambda_1 + \mu_1 \lambda_2 + \mu_2^2 \left(\frac{\lambda_1}{\mu_1 - \lambda_1}\right)\right]. \tag{A3}$$

Let the first term $= X$; then

$$\partial X / \partial \lambda_1 = \frac{\mu_2 \lambda_2 c}{(\mu_1 \mu_2 - \mu_2 \lambda_1 - \mu_1 \lambda_2)^2}. \tag{A4}$$

The two righthand terms of (A3) simplify to:

$$\left[\lambda_1 + \frac{\mu_1}{\mu_2} \lambda_2\right] + \left[\mu_2 \left(\frac{\lambda_1}{\mu_1 - \lambda_1}\right)\right]. \tag{A5}$$

Let $B5 = Y$; then

$$\partial Y / \partial \lambda_1 = 1 + \left[\frac{\mu_2(\mu_1 - \lambda_1) + \mu_2 \lambda_1}{(\mu_1 - \lambda_1)^2}\right] \tag{A6}$$

$$\partial C / \partial \lambda_1 = \partial X / \partial \lambda_1 \cdot Y + \partial Y / \partial \lambda_1 \cdot X = \tag{A7}$$

$$\left\{\left[\frac{\mu_2 \lambda_2 c}{(\mu_1 \mu_2 - \mu_2 \lambda_1 - \mu_1 \lambda_2)^2}\right] \cdot \left[\lambda_1 + \frac{\mu_1}{\mu_2} \lambda_2 + \mu_2 \left(\frac{\lambda_1}{\mu_1 - \lambda_1}\right)\right]\right\} +$$

$$\left\{\left[1 + \frac{\mu_2(\mu_1 - \lambda_1) + \mu_2 \lambda_1}{(\mu_1 - \lambda_1)^2}\right] \cdot \left[\frac{\lambda_2 c}{(\mu_1 \mu_2 - \mu_2 \lambda_1 - \mu_1 \lambda_2)}\right]\right\}$$

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