ON THE ECONOMIES OF DEVELOPING COUNTRIES

by

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PREFACE

In a society of living things, save human beings, hierarchy among its members is typically determined by physical power. Be they ants, fish, or lower primates, the ones with physical superiority subjugate the other members in each society. That is the working of nature, and all members, including those who dominate, are ruled by this mechanism, which is beyond their control. We, human beings, differ in that we can be conscious not only of our actions, but also of our thoughts and motivations behind them. Our consciousness has aided us in our realization that an arrangement which allows us to act as if we had equal physical power can function more effectively than one which requires society's members' incessant application of own physical power to ensure a certain status among each other. As celebral capability became as important as, if not more important than, corporal capability, the arrangement was broadened to include limitation to dominancy by mental power and wealth as well. Protection of human dignity and rights, and universal suffrage are manifestations of such realizations. Voluntary curtailment of power in order to lessen power struggle and to devote our energy to some other purposes is what distinguishes humans from other living beings, and is the core of civilization.

The definition of members to which this principle applies was a narrow one at the beginning. There have always been privileged subgroups in every society within which the arrangement is more rigorously upheld, and who regarded the rest of the society not worth the concession of power. Our history testifies that the privileged subgroups are becoming more aware of the fact that they are separated from the underprivileged mainly by sheer coincidence; none of us has had the freedom to fully determine our own atheletic, intellectual, and monetary endowments. In many countries, an increasing number of previously underprivileged subgroups have been added to the group, whose members include those who have the potential to conquer others in some ways, and in which the commitment to egality is observed.

The international society has lagged behind in this regard, hampered by differences in systems and values. So far, countries with material and/or military prowess have been able to assert their stance and secure their positions in the international community. Considering that materialism has had tremendous and universal appeal to people and that military domination is possible only through mastery of advanced technology, it seems that economic development and success will continue to be a necessary minimum condition for a country to gain some membership in the community. Without a country's full membership in the international community, there is little respect for its people and their *modi vivendi* in the international arena. This dissertation was written with the aim to be a modest stone, laid as a part of the foundation of the agenda of mutual respect among all human beings.

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CHAPTER I

Implications of Terms-of-Trade Uncertainty on Economic Growth and Business Cycles

Introduction

This essay examines the effects of uncertain terms-of-trade in both the long and the short run, namely the consequences on economic growth and business cycles. For the joint study of these two phenomena, we use a theoretical model whose basic form can be traced back to a neoclassical growth model. We conduct theoretical investigations of economic growth and business cycles, as well as an empirical investigation of the latter; terms-of-trade data is available for a twenty-year period, permitting empirical examination only for short-run implications.

The theoretical investigation of long-run effects bears upon the assertion by the United Nations (1952, p. 1; 1953, p. 7-11, 16; 1958, p. 64) that terms-of-trade instability and uncertainty discourage economic growth.[1] The UN argument starts by directing attention to the wild fluctuations in export earnings of developing countries. A fluctuation in export

[1] Strictly speaking, economic instability and uncertainty are not synonymous; the price level, for instance, can in principle be unstable and perfectly predictable at the same time. However, it is often the case in reality that an unstable economic variable is regarded as uncertain. Thus, we will not differentiate between instability and uncertainty.

earnings may originate from any combination of instability in demand for, supply of, and price of an export commodity. The focus is placed on the large swings of the prices of primary goods—which is what developing countries typically export—relative to prices of manufactured goods. For a developing country that exports primary goods and imports capital goods, such a phenomenon means unstable terms-of-trade and purchasing power, hampering investment and, consequently, economic growth.[2] Since variance is a measure associated with a certain time period, the effect of its changes is a long-run issue. Considering a recent empirical study of cross-country data (Levine and Renelt, 1990) which found that average output growth rates are positively and robustly related to share of investment in GDP, investment appears to be an important economic variable, which should be examined together with economic growth. Lately, the World Bank (1994, p. 55-56) has also re-emphasized the significance of effects of commodity-price volatility on private investment and economic growth. We examine the assertion by the United Nations through constructing a theoretical model for a small, open economy.

The short-run investigation is built on the particular feature of our model that a terms-of-trade jump is cast as an exogenous shock to the production of a small, open economy. Terms-of-trade shocks have the great advantage over conventional productivity shocks of being directly measurable, and hence have the potential for providing stricter tests for equilibrium growth/business-cycle models than the fluctuations obtained from the Solow residual.[3] The model employs a production function that is linear in capital, and hence does not allow a steady-state solution. Put differently, our analysis does not distinguish long run from short run in the manner that models with steady-states do; long-run results in our model

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[2] Caine (1954) pointed out that higher variation in income may result in a higher savings rate, but not necessarily in a lower level of investment.

[3] The potential of a terms-of-trade jump as a directly-measurable exogenous shock that explains real business-cycles has been called to the attention by McCallum (1989) and Plosser (1989).

are finite accumulations of short-run results. Therefore, we regard our model as suitable for analyzing both economic growth and business cycles.[4] Recalling that economic growth and business cycles are often associated with "trends" and "fluctuations", respectively, our stance endorses the one taken by Hicks (1965, p. 4). As pointed out by Plosser (1989), Hicks claimed that the distinction between trend and fluctuation is a statistical one, and that we cannot assume the existence of fundamentally different economic forces corresponding to trend and fluctuation, respectively.[5]

Our model economy specializes completely in the production of one export good, and imports all goods for consumption and investment. The model economy is examined through a representative producer/consumer, who maximizes profit and utility (with a constant relative-risk-aversion rate). We adopt Romer's (1987) view of knowledge embodied in capital, and the so-called AK technology assumption enables the model economy to exhibit endogenous growth. Moreover, the AK production function permits an analytical solution to the model.[6] Therefore, we are not forced to resort to a linear approximation around a steady state, whose degree of accuracy may be low (Correia, Neves, and Rebelo, 1995). Furthermore, an analytical solution provides a means to estimate relative-risk-aversion rates. Trade is assumed always balanced, and there is no financial capital flow. Our model differs from conventional business-cycle models in that we abstract from labor supply decisions of an agent. In other words, by adoption of the AK technology assumption, and of the

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[4] The capability of real-business-cycle models to analyze both growth and business cycles was pointed out by Prescott (1986), Stock and Watson (1988), Plosser (1989), and Rotemberg and Woodford (1994).

[5] Singleton (1988) is also in favor of studying the secular and cyclical components jointly, naming the likelihood of an economic decision to influence both components at the same time as one of the reasons. Previous empirical studies that were aimed at establishing the negative relationship between export earning instability and economic growth among developing countries (MacBean, 1966; Kenen and Voivodas, 1972; Glezakos, 1973; Voivodas, 1974) did not agree on the measurement of export instability or export trend. The disagreement may well be the reason why their conclusions were at variance with each other.

[6] According to Singleton (1988), one of the major obstacles to studying equilibrium business-cycle models is that they do not yield analytical solutions.

terms-of-trade jump as the exogenous shock, we attempt to avoid some of the controversial aspects of conventional real-business-cycle models, such as negative technological shocks, the implication of a strong correlation between the marginal productivity of labor and hours worked,[7] and the substitution of goods and leisure as the critical element in explaining economic fluctuations.

The long-run effects of uncertain terms-of-trade on investment and economic growth are theoretically examined for a specific terms-of-trade behavior: the logarithm of terms-of-trade is an independently and identically distributed (i.i.d.) Gaussian process with structural breaks. We assume that a representative agent views terms-of-trade as a string of distinct log-normal processes, with only one process being realized at a time, and that the agents regard the logarithm of terms-of-trade as normally distributed, with specific values for the mean and variance. When a terms-of-trade value is realized that is hard to reconcile with the log-normal distribution with currently believed mean and variance, the agents are taken by surprise and revise their expectations (the mean and variance) in accordance with the new distribution. Our results illustrate that the assertion by the United Nations may be valid; a large terms-of-trade variance may discourage investment and growth in the long run, depending on the magnitude of risk-aversion-rate relative to unity. We also find that investment and output growth rates are linear functions of the level of terms-of-trade in the short run, where a structural break in the terms-of-trade process results in a change in the slope of the functions.

For the empirical verification of the short-run effects implied by our model, twenty countries were selected, whose economies are characterized by their high involvement in in-

[7] Such an implication is obtained when the exogenous shock impacting the economy in real-business-cycle models is a productivity shock. Christiano and Eichenbaum (1992) were able to reproduce low correlation between labor productivity and hours worked using government consumption shocks. However, Cardia (1991) compared the powers of productivity, monetary, and fiscal shocks in reproducing the statistical characteristics of the actual economic time-series, and concluded that productivity shocks were superior by far.

ternational trade (Cape Verde, Congo, Gabon, Gambia, Mauritania, Mauritius, Seychelles, Barbados, Guyana, Jamaica, Hong Kong, Jordan, Malaysia, Singapore, Belgium, Cyprus, Ireland, Malta, the Netherlands, and Papua New Guinea). Detrending the same data with differing trends is known to produce inconsistent economic implications (Singleton, 1988; Stock and Watson, 1988), and there is no explicit theoretical support for any particular trend (Stock and Watson, 1988). Hence, the data was not detrended in the empirical investigation. Three exercises were carried out, namely characterization of terms-of-trade as time series, estimation of relative-risk-aversion rates, and simulation of growth rates.

Positive correlations between output and investment growths, in addition to positive correlations between output and consumption growths, were observed in the data, and the theoretical model was able to reproduce such relationships. However, the output and investment growth rates implied by the model did not replicate the actual rates very well. Most critically, the oil shocks in the periods around 1973-1974 and 1979-1980 were left unexplained with our terms-of-trade as the source of exogenous shocks. Success of business-cycle models in replicating the actual growth rates of various variables has been reported in cases with productivity shocks that are calculated from Solow residuals (e.g. Plosser, 1989, for a closed economy, and Cardia, 1991, for a small open economy). Other shocks, such as monetary and fiscal shocks, have not been as good as productivity shocks in reproducing the actual economy, and productivity shocks that are persistent have been highlighted as the key to success (Cardia, 1991; Correia, Neves, and Rebelo, 1995). However, our productivity shock derived from terms-of-trade was also persistent. We note that the Solow residual is highly correlated with the growth rate of output (Mankiw, 1989; Cardia, 1991), while terms-of-trade growth has shown not to be. It appears, at least at this point, that a high correlation between productivity shock and output may be necessary for real business-cycle models to be able to replicate actual economies well.

The Model

Description of the Model

We consider an economy that consists of identical individuals with infinite lives. Every agent participates in the economy as both a producer and a consumer. The size of the population is constant. The economy is capable of producing only one commodity, which is entirely exported, so that consumption and investment goods must be imported in return. The production technology exhibits constant returns to scale. More specifically, we employ a production function that is linear in capital per capita, which enables the economy to grow endogenously. The rate of capital depreciation is assumed to be unity.[8] The export goods market is perfectly competitive. As the economy is small, we may regard the terms-of-trade (the price of output over aggregate price of imports) as an exogenously given random variable whose current value is known with certainty. There is neither capital inflow nor outflow, which rules out the possibility of risk diversification through the international capital market.

We assume that the total production, Y_t, has three inputs: capital, labor, and knowledge embodied in capital, as in Romer (1987). Hence, Y_t has the following form:[9]

$$Y_t = ({K_t}^{\lambda}{L_t}^{1-\lambda}){K_t}^{\theta},$$

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[8] Our model draws on the model proposed by Levhari and Srinivasan (1969), as well as that by Brock and Mirman (1972). Levhari and Srinivasan modeled a household's optimal saving behavior when confronted with two options regarding its wealth: to consume, or to make an investment whose rate of return is uncertain. Rebelo (1992) also worked on the model by Levhari and Srinivasan through adding productive activities, and analyzed the effects of uncertain return to investment on growth. He was able to carry out an analysis with a capital depreciation rate less than unity, due to the fact that the production function was linear in capital and that the stochastic variable appeared in a way analogous to that in the model by Levhari and Srinivasan. The stochastic variable in our model, namely terms-of-trade, affects not only investment but also consumption, and an analytical solution is possible only when the depreciation rate is equal to unity.

[9] All superscripts denote exponentiation.

where K_t: amount of capital applied to production in period t,

L_t: amount of labor applied to production in period t,

K_t^{θ}: amount of knowledge embodied in capital in period t,

λ, θ: positive constants smaller than unity.

The problem an individual faces as a producer in the above economy is to maximize profits at time t:

$$\max_{k_t} \quad \pi_t \equiv y_t - r_t k_t - w_t \,,$$

$$\text{subject to} \qquad y_t \leq f(k_t)\,, \tag{1.1}$$

where y_t: amount of per-capita output (export goods) in period t,

k_t: amount of per-capita capital in period t,

$f(k_t)$: per-capita production in period t,

π_t: profits (expressed in terms of export goods) per capita in period t,

r_t: rental price of capital (expressed in terms of export goods) in period t,

w_t: wage (expressed in terms of export goods) in period t.

We assume that the price of the product is positive at all times and that the producer in a perfectly-competitive market supplies the entire production to the market in each period, so that strict equality holds in Equation (1.1): $y_t = f(k_t) = r_t k_t + w_t$. Under the assumption that $\lambda + \theta$ is equal to unity (i.e. linearity in k_t) and that the amount of labor applied to production is fixed at L, we obtain:

$$f(k_t) = a k_t \,,$$

where a is a positive constant, equal to $L^{-\lambda}$. This production function allows us to obtain an analytical solution to the Bellman equation (1.2) given below. Moreover, the form of the production function implies that the rental price of capital and the wage are equal to a and zero, respectively. Hence, fixing the amount of labor is equivalent to abstracting from the representative agent's decision making on the matter of labor supply; we do not explicitly consider labor as an input to production in our dynamic framework.

The problem an individual faces as a consumer in the above economy is to maximize the time-discounted stream of expected utility at time t:

$$\max_{c_t} \quad E_t[\sum_{\tau=t}^{\infty} \beta^{\tau-t} u(c_\tau)|k_t, p_t] \tag{1.2}$$

$$\text{subject to} \qquad c_\tau + i_\tau \leq p_\tau[r_\tau k_\tau + w_\tau] + p_\tau \pi_\tau \,,$$

$$\pi_\tau = 0 \,,$$

$$y_\tau = f(k_\tau) = r_\tau k_\tau + w_\tau \,,$$

$$k_{\tau+1} = i_\tau \,,$$

$$c_\tau \geq 0 \,, k_\tau \geq 0 \,, k_0 \text{ given,}$$

where E_t: expectation operator given information available at time t,

p_t: price of output over imported goods price (terms-of-trade),

c_τ: amount of per-capita consumption in period τ,

i_τ: amount of per-capita investment in period τ,

u: utility function of individual consumer,

β: rate of time discount ($0 < \beta < 1$).

We will assume that the resources are fully utilized, and hence that the first constraint binds, i.e. $c_\tau + i_\tau = p_\tau y_\tau$. In solving Problem (1.2), we make use of the fact that a solution to the problem can be given as a value function, $V(k_t, p_t)$, subject to the constraint set of Problem (1.2):

$$\begin{aligned} V(k_t, p_t) &= \max_{c_t} \quad E_t[\sum_{\tau=t}^{\infty} \beta^{\tau-t} u(c_\tau)|k_t, p_t] \\ &= \max_{c_t} \quad \{u(c_t) + \beta E_t[V(k_{t+1}, p_{t+1})|k_t, p_t]\} \,. \end{aligned} \tag{1.3}$$

We choose a commonly-used type of utility function with a constant relative-risk-aversion rate, α ($\alpha > 0, \alpha \neq 1$): $u(c_t) = \frac{c_t^{1-\alpha}}{1-\alpha}$. The chosen function belongs to the family of hyperbolic absolute risk aversion (HARA) utility functions, which enables us to obtain an explicit solution. For the purpose of obtaining clear implications from the model, we consider terms-of-trade that is independently and identically distributed. Following Manuelli and Sargent (1987, p. 6-8), we assume that $V(k_t, p_t)$ has the following form:

$$V(k_t, p_t) = z \cdot (ap_t k_t)^{1-\alpha}, \tag{1.4}$$

where z is a positive constant. Note that Equations (1.3) and (1.4) allow us to write $V(k_t, p_t)$ also as follows:

$$V(k_t, p_t) = \max_{c_t} \left\{ \frac{c_t^{1-\alpha}}{1-\alpha} + \beta(ap_t k_t - c_t)^{1-\alpha} z a^{1-\alpha} E_t(p_{t+1}^{1-\alpha}) \right\}. \tag{1.5}$$

Taking the derivative with respect to c_t of the expression inside the curly brackets of Equation (1.5) and setting it equal to zero, we obtain the maximizing condition:

$$c_t^{-\alpha} - \beta(ap_t k_t - c_t)^{-\alpha} z a^{1-\alpha}(1-\alpha) E_t(p_{t+1}^{1-\alpha}) = 0.$$

Thus, under the assumption that both terms-of-trade and amount of capital are always positive, per-capita consumption is given as follows:

$$\begin{aligned} c_t &= \{\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})\}^{-\frac{1}{\alpha}}[1 + \{\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})\}^{-\frac{1}{\alpha}}]^{-1} ap_t k_t \\ &= \zeta a p_t k_t, \end{aligned} \tag{1.6}$$

where ζ is equal to $\{\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})\}^{-\frac{1}{\alpha}}[1 + \{\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})\}^{-\frac{1}{\alpha}}]^{-1}$. From Equations (1.4) and (1.5), we see that the equation below holds:

$$z \cdot (ap_t k_t)^{1-\alpha} = \frac{c_t^{1-\alpha}}{1-\alpha} + \beta(ap_t k_t - c_t)^{1-\alpha} z a^{1-\alpha} E_t(p_{t+1}^{1-\alpha}), \tag{1.7}$$

where c_t is the optimal amount of consumption given as Equation (1.6). Equation (1.7) can be further modified as follows:

$$(1-\alpha) \cdot z \cdot (ap_t k_t)^{1-\alpha} = \zeta^{1-\alpha} \cdot (ap_t k_t)^{1-\alpha} + \eta \cdot (1-\zeta)^{1-\alpha} \cdot (ap_t k_t)^{1-\alpha}, \tag{1.8}$$

where η is equal to $\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})$, and $\zeta = \frac{\eta^{-1/\alpha}}{1+\eta^{-1/\alpha}}$ holds. The above equation can be modified as follows:

$$(1-\alpha)z = \zeta^{1-\alpha} + \eta \cdot (1-\zeta)^{1-\alpha} = \eta \cdot (1+\eta^{\frac{-1}{\alpha}})^{\alpha}.$$

Hence, the following equation holds:

$$\begin{aligned}(1-\alpha)^{\frac{-1}{\alpha}} z^{\frac{-1}{\alpha}} &= \eta^{\frac{-1}{\alpha}}(1+\eta^{\frac{-1}{\alpha}})^{-1} \\ &= (1-\alpha)^{\frac{-1}{\alpha}} z^{\frac{-1}{\alpha}} \beta^{\frac{-1}{\alpha}} a^{\frac{-(1-\alpha)}{\alpha}} E_t(p_{t+1}^{1-\alpha})^{-\frac{1}{\alpha}}\}(1+\eta^{\frac{-1}{\alpha}})^{-1}.\end{aligned}$$

The above equation is equivalent to:

$$1+\eta^{\frac{-1}{\alpha}} = \beta^{\frac{-1}{\alpha}} a^{\frac{-(1-\alpha)}{\alpha}} E_t(p_{t+1}^{1-\alpha})^{-\frac{1}{\alpha}}.$$

Considering that η is equal to $\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})$, we obtain the following expressions for z and ζ:

$$z = \frac{\{1-\beta^{\frac{1}{\alpha}} a^{\frac{(1-\alpha)}{\alpha}} E_t(p_{t+1}^{1-\alpha})^{\frac{1}{\alpha}}\}^{-\alpha}}{1-\alpha}, \tag{1.9}$$

$$\begin{aligned}\zeta &= \{\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})\}^{-\frac{1}{\alpha}}[1+\{\beta z a^{1-\alpha}(1-\alpha)E_t(p_{t+1}^{1-\alpha})\}^{-\frac{1}{\alpha}}]^{-1} \\ &= 1-\{\beta^{\frac{1}{\alpha}} a^{\frac{(1-\alpha)}{\alpha}} E_t(p_{t+1}^{1-\alpha})^{\frac{1}{\alpha}}\}.\end{aligned} \tag{1.10}$$

Therefore, Equation (1.6) is satisfied when c_t and i_t are given by the following expressions:

$$c_t = [1-\{\beta^{\frac{1}{\alpha}} a^{\frac{(1-\alpha)}{\alpha}} E_t(p_{t+1}^{1-\alpha})^{\frac{1}{\alpha}}\}]p_t y_t, \tag{1.11}$$

$$i_t = k_{t+1} = \{\beta^{\frac{1}{\alpha}} a^{\frac{(1-\alpha)}{\alpha}} E_t(p_{t+1}^{1-\alpha})^{\frac{1}{\alpha}}\}p_t y_t. \tag{1.12}$$

If the solution (given by Equations (1.11) and (1.12)) is to be feasible, both consumption and investment should be positive fractions of income. That is, we need:

$$\beta a^{1-\alpha} E_t(p_{t+1}^{1-\alpha}) < 1. \tag{1.13}$$

Since $a p_{t+1}$ is equal to $(p_{t+1} y_{t+1})/i_t$, the feasibility condition can be interpreted roughly as follows. When the expected return on investment over a single period is high, the agents must be discounting the future heavily, focusing mostly on the immediate future. When the return is low, they must be looking further into the future. We assume that Equation (1.13) holds and that the solution given above is indeed feasible. Under this assumption, the consumption function given by Equation (1.11) is the unique optimal solution to Problem (1.2). This can be deduced from the facts that the feasibility condition and the assumption on the form of the utility function $\left(\frac{\partial u}{\partial c_t}\Big|_{c_t=0} = \infty \right)$ make the second derivative of the objective function (with respect to c_t) in Problem (1.2) negative for all positive values of c_t, and that its constraint set is linear in c_t.

Now we consider the case in which the agents continue to view the stochastic variable, p_t, to be independently, identically, and log-normally distributed, but in which there are actually unexpected structural breaks. Each period is determined by two successive structural breaks, and characterized by mean μ_s and variance σ_s^2, where s denotes the period determined by the log-normality of p_t.[10] That is, an integer value of s corresponds to a period between two consecutive changes in the distribution of p_t. It follows that terms-of-trade is characterized by the following equations:

$$E(p_t) = e^{\mu_s + \sigma_s^2/2} \equiv \bar{p}_s \,,$$

$$Var(p_t) = \bar{p}_s^2 (e^{\sigma_s^2} - 1) \,,$$

$$E(p_t^{1-\alpha}) = \bar{p}_s^{1-\alpha} e^{\frac{\alpha(\alpha-1)}{2}\sigma_s^2} \,, \tag{1.14}$$

where $\bar{p}_s$: mean value of terms-of-trade in period s,

t: time in period s.

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[10] As summarized by Hansen and Singleton (1983), the combination of a utility function with a constant relative-risk-aversion rate and stochastic returns with log-normal distributions has been widely adopted in capital asset pricing models, whose setting bears resemblance to the model presented here. They point out that these functional forms are popular since they together allow analytical and empirically tractable optimality conditions.

While the agents believe the terms-of-trade to have an unchanging distribution, there can be a sudden, unexpected change in the terms-of-trade behavior, through which mean and variance values change while the distribution remains log-normal. Such changes are correctly recognized by the rational agents, and the mean and variance are revised accordingly and used for predicting the future. After the revision, the agents again expect the distribution with the renewed specification to last forever; s denotes a period between two such revisions. When there is no change in the distribution of $\ln p_t$, the equality $E_t(p_{t+1}^{1-\alpha}) = E(p_{t+1}^{1-\alpha}) = \bar{p}_s^{1-\alpha} e^{\frac{\alpha(\alpha-1)}{2}\sigma_s^2}$ holds, where $t, t+1 \in s$, since the p_t's are independent. Even when there is a change in the distribution between times t and $t+1$, the agents continue to assume that the following holds: $E_t(p_{t+1}^{1-\alpha}) = E(p_t^{1-\alpha}) = \bar{p}_s^{1-\alpha} e^{\frac{\alpha(\alpha-1)}{2}\sigma_s^2}$, where time t belongs to period s and $t+1$ to the next.

The equations for per-capita consumption and investment have the following forms:

$$c_t = [1 - \{\beta^{\frac{1}{\alpha}} a^{\frac{1-\alpha}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2}\}] p_t y_t \,, \tag{1.15}$$

$$i_t = k_{t+1} = \{\beta^{\frac{1}{\alpha}} a^{\frac{1-\alpha}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2}\} p_t y_t \,. \tag{1.16}$$

According to Equation (1.16) and the relationship $y_t = ak_t$, the growth rates of investment and output per capita can be expressed as follows:

$$\frac{i_t}{i_{t-1}} = \frac{k_{t+1}}{k_t} = \beta^{\frac{1}{\alpha}} a^{\frac{1}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2} p_t \,, \tag{1.17}$$

$$\frac{y_{t+1}}{y_t} = \frac{ak_{t+1}}{ak_t} = \beta^{\frac{1}{\alpha}} a^{\frac{1}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2} p_t \,. \tag{1.18}$$

From Equations (1.4), (1.9), and (1.14), we see that the value function will be:

$$\begin{aligned} V(k_t, p_t) &= z \cdot (ap_t k_t)^{1-\alpha} \\ &= \frac{(ap_t k_t)^{1-\alpha}}{1-\alpha} \left[1 - \beta^{\frac{1}{\alpha}} a^{\frac{1-\alpha}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2}\right]^{-\alpha} . \end{aligned}$$

Long-Run and Short-Run Implications

We will now consider the long-run effects of a greater variance in terms-of-trade when its mean remains at the same level.

Equations (1.16) and (1.17) yield the following:

$$\frac{\partial i_t}{\partial \sigma_s^2} = \frac{\partial k_{t+1}}{\partial \sigma_s^2} = \frac{(\alpha-1)}{2}\beta^{\frac{1}{\alpha}} a^{\frac{1-\alpha}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2} p_t y_t , \tag{1.19}$$

$$\frac{\partial\left(\frac{i_t}{i_{t-1}}\right)}{\partial \sigma_s^2} = \frac{\partial\left(\frac{k_{t+1}}{k_t}\right)}{\partial \sigma_s^2} = \frac{\partial\left(\frac{y_{t+1}}{y_t}\right)}{\partial \sigma_s^2} = \frac{(\alpha-1)}{2}\beta^{\frac{1}{\alpha}} a^{\frac{1}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2} p_t . \tag{1.20}$$

Equations (1.19) and (1.20) imply that when the rate of relative-risk-aversion is less than unity, a terms-of-trade with larger variance reduces investment and growth. When the rate exceeds unity, such terms-of-trade will lead to larger investment and hence faster output growth. In other words, the model does not support the idea that a fluctuating terms-of-trade universally hinders economic growth.

The wish to avoid risks works in two opposite directions when the agent is faced with uncertain terms-of-trade.[11] A rate smaller than unity corresponds to the case in which the economy prefers to consume more when otherwise invested resources give only uncertain return. The other case interprets an increase in uncertainty differently. If the terms-of-trade becomes uncertain, an economy with risk aversion rate bigger than unity prefers to save more and prepare for the worst. However, an increase in terms-of-trade variance decreases utility of agents in both types of economies, as the following equation indicates:

$$\frac{\partial V(k_t,p_t)}{\partial \sigma_s^2} = \frac{-\alpha}{2}(a p_t k_t)^{1-\alpha}[\beta^{\frac{1}{\alpha}} a^{\frac{1-\alpha}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2}][1-\beta^{\frac{1}{\alpha}} a^{\frac{1-\alpha}{\alpha}} \bar{p}_s^{\frac{1-\alpha}{\alpha}} e^{\frac{(\alpha-1)}{2}\sigma_s^2}]^{-\alpha-1} .$$

The above derivative is negative for all degrees of risk aversion when the solutions are feasible. Regarding the short-run effects of uncertain terms-of-trade, where mean and variance

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[11] When $\alpha < 1$ holds, u becomes unbounded above and bounded below. When $\alpha > 1$ holds, u is bounded above and unbounded below. This can be interpreted as the minimum utility being secured when $\alpha < 1$ holds, and the maximum utility being limited when $\alpha > 1$ holds (comment made by David Cole and quoted in Hahn, 1970).

are considered fixed, Equation (1.17) indicates that short-run changes in investment growth rate are governed by those of terms-of-trade level, as long as there is no change in the distribution of terms-of-trade. Due to our AK technology assumption, the output growth rate behaves just like investment growth rate, but with a lag.

Empirical Investigation of Short-Run Implications

We examine how well a change in terms-of-trade, acting as an exogenous productivity shock, explains business cycles, as discussed in the Introduction.

Data Description

Considering the assumptions on which the theory was built, countries with considerable involvement in international trade were selected for empirical investigation. "Openness" as defined by Summers and Heston (1991)[12] and availability of other necessary data were used as the criteria for the selection. The following twenty countries, whose values for openness were larger than 0.8 on average in the period of 1971-1990, were selected: Cape Verde, Congo, Gabon, Gambia, Mauritania, Mauritius, Seychelles, Barbados, Guyana, Jamaica, Hong Kong, Jordan, Malaysia, Singapore, Belgium, Cyprus, Ireland, Malta, the Netherlands, and Papua New Guinea. The table in Appendix A lists the major import and export commodities of these countries in 1990. The terms-of-trade data for the period of 1971-1990 were obtained from the World Tables 1993 (World Bank, 1993), and all other data from The Penn World Table (Mark 5) (Summers and Heston, 1991). The available terms-of-trade was a price ratio index: export prices (f.o.b.) over import prices (c.i.f.), normalized with their 1987 values.[13]

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[12] "Openness" is defined as the sum of the amounts of exports and imports divided by the amount of output, all of which are evaluated using current international prices.

[13] World Bank (1993) explains it as "the relative level of export prices compared with import prices, calculated as the ratio of a country's index of the average export price to the average import price index".

Characterization of Terms-of-Trade

We begin by investigating whether the assumption made in the theoretical section, i.e. the description of terms-of-trade sequences as an i.i.d. Gaussian process with structural breaks, is appropriate.

Characterization of terms-of-trade as such a process was carried out by applying the Pettitt's nonparametric test for change-point detection (Pettitt, 1979).[14] The test was applied recursively until each process consisted of too little data to allow further change-point testing. After this treatment, the Kolmogorov-Smirnov test was applied in order to confirm the distinctness of successive processes.[15] It was judged that two successive processes belong to populations of different distributions when the Kolmogorov-Smirnov test rejected its null hypothesis at the significance level of 5%.[16] Subsequently, every process was examined for log-normality using the Shapiro-Wilk test. Finally, the mean (μ_s) and the variance (σ_s^2) of each process (labeled s) were calculated. The results are shown in Table 1.1. As indicated in the table, the terms-of-trade could be represented well as a string of log-normal distributions.[17]

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[14] Let a sequence of random variables be represented by X_t's where $t = 1, 2, \ldots, T$. Suppose that the event sets $\{X_t | t = 1, \ldots, \tau\}$ and $\{X_t | t = \tau + 1, \ldots, T\}$ are generated by distribution functions, $F_1(x)$ and $F_2(x)$, respectively. If the two distribution functions, $F_1(x)$ and $F_2(x)$, are different, then $t = \tau$ is a change point. The null hypothesis, $H_0 : \tau = T$, is tested against the alternative, $H_1 : 1 \leq \tau < T$. The test statistic makes use of the fact that the random variables from the same distribution function are indeed randomly realized. The test statistic values given by Castellan (Siegel and Castellan, 1988, p. 339-346) were used. Terms-of-trade for Bahrain, Kuwait, Saudi Arabia, and United Arab Emirates during the period 1971-1990 were also examined using Pettitt's test. The test identified three points (1973-1974, 1979-1980, and 1985-1986) as change points for all four countries, and hence successfully detected the oil shocks.

[15] The Kolmogorov-Smirnov test compares the cumulative density functions of two samples for detection of any difference between the distributions of the corresponding populations. The null hypothesis is that the distributions are the same and the alternative hypothesis is that they are not.

[16] Whenever the number of years in each subperiod was enough to conduct a runs test for randomness, the null hypothesis that the variable be random was not rejected at 10% significance level against the alternative hypothesis that the variable not be random.

[17] The few periods that did not conform to log-normality were nonetheless used in the estimation of the risk aversion rate, due to the scarcity of data.

Table 1.1: Characterization of Terms-of-Trade

Country	ln(Terms-of-Trade)		
Period	Mean[a]	Var.[a] ($\times 10^{-2}$)	Normal Distrib.
Cape Verde			
1971 - 79	3.97	2.47	yes
1980 - 86	4.43	0.18	yes
1987 - 90	4.62	1.99	yes
Congo			
1971 - 78	4.62	3.68	no
1979 - 85	4.99	1.42	no
1986 - 90	4.50	4.05	yes
Gabon			
1971 - 73	3.92	1.36	yes
1974 - 78	4.60	0.32	yes
1979 - 85	4.98	1.69	yes
1986 - 90	4.52	0.50	yes
Gambia			
1971 - 74	5.23	3.87	no
1975 - 79	4.98	0.74	yes
1980 - 90	4.73	1.06	yes
Mauritania			
1971 - 77	4.98	2.50	yes
1978 - 90	4.69	0.37	yes
Mauritius			
1971 - 73	4.49	1.99	yes
1974 - 78	4.80	2.68	yes
1979 - 85	4.45	0.36	yes
1986 - 90	4.59	0.09	yes
Seychelles			
1971 - 73	4.40	2.80	yes
1974 - 78	4.76	1.14	yes
1979 - 84	5.01	0.90	yes
1985 - 90	4.78	3.83	yes
Barbados			
1971 - 72	4.61	1.10	no
1973 - 81	5.00	2.28	yes
1982 - 90	4.79	0.64	yes
Jamaica			
1971 - 79	4.78	0.18	yes
1980 - 90	4.59	0.41	yes
Guyana			
1971 - 75	5.22	0.91	yes
1976 - 81	4.92	0.67	yes
1982 - 90	4.58	0.56	no
Hong Kong			
1971 - 77	4.83	0.68	yes
1978 - 85	4.58	0.14	yes
1986 - 90	4.62	0.02	yes
Jordan			
1971 - 79	4.76	1.42	yes
1980 - 85	4.58	0.07	yes
1986 - 90	4.68	0.40	yes
Malaysia			
1971 - 84	4.79	0.66	yes
1985 - 90	4.61	0.67	yes
Singapore			
1971 - 73	4.32	0.48	yes
1974 - 80	4.56	0.08	yes
1981 - 90	4.60	0.01	yes
Belgium			
1971 - 75	4.89	1.58	yes
1976 - 80	4.72	0.07	yes
1981 - 90	4.57	0.13	yes
Cyprus			
1971 - 73	4.93	1.24	yes
1974 - 78	4.65	0.06	yes
1979 - 85	4.54	0.15	no
1986 - 90	4.63	0.25	yes
Ireland			
1971 - 74	4.86	3.28	yes
1975 - 79	4.58	0.08	yes
1980 - 85	4.47	0.86	yes
1986 - 90	4.60	0.06	no
Malta			
1971 - 77	4.68	0.65	yes
1978 - 87	4.58	0.42	yes
1988 - 90	4.70	0.01	yes
Netherlands			
1971 - 74	4.88	2.00	yes
1975 - 80	4.72	0.28	yes
1981 - 90	4.62	0.04	no
Papua New Guinea			
1971 - 79	4.98	1.67	yes
1980 - 90	4.66	1.19	yes

[a] Mean and variance correspond to μ_s and σ_s^2, respectively.

Persistence of Shocks

Our investigation is conducted within the framework that shocks to the economy are represented by jumps in terms-of trade. For the sake of mathematical tractability, we regard the logarithm of terms-of-trade as an i.i.d. variable with changing regimes. However, it is possible to represent the time-series of terms-of-trade with other data-generating models. In order to investigate the degree of shock persistence as it is usually done in the real-business-cycle literature, the time-series properties of terms-of-trade itself (and not of the logarithm of terms-of-trade) were also examined.

The sample autocorrelation and partial autocorrelation functions of p_t exhibited the characteristics of an AR(1) process; autocorrelation function values declined rapidly and partial autocorrelation function values had spikes at lag 1 only. The sample autocorrelation function values with lag 1 were as follows: Cape Verde 0.80, Congo 0.64, Gabon 0.72, Gambia 0.60, Mauritania 0.54, Mauritius 0.54, Seychelles 0.54, Barbados 0.56, Grenada 0.70, Jamaica 0.70, Guyana 0.86, Hong Kong 0.83, Jordan 0.52, Malaysia 0.52, Singapore 0.63, Belgium 0.79, Cyprus 0.63, Ireland 0.68, Malta 0.52, the Netherlands 0.57, and Papua New Guinea 0.65. Although we do not have sufficient information to conclude that AR(1) is the best model to describe terms-of-trade movements, we may infer that p_t is highly persistent.

The fact that p_t shows persistence is consistent with our framework, in which $\ln p_t$ is considered to be an i.i.d. variable. If clusters of values of $\ln p_t$ are determined by the same distribution function, the corresponding values of p_t are likely to be closer to each other than in the case that $\ln p_t$ values would have been drawn from different distribution functions. Thus, the length of each regime may be considered a measure of shock persistence, and Table 1.1 shows that terms-of-trade is indeed persistent.

Estimation of Relative-Risk-Aversion Rate

For the estimation of risk aversion rate, Equation (1.16) was normalized as follows:[18]

$$\ln \frac{\frac{i_t}{p_t y_t}}{\frac{i'_{87}}{p'_{87} y'_{87}}} = \frac{1-\alpha}{\alpha} \ln \frac{\bar{p}_s}{\bar{p}'_{87}} + \frac{(\alpha - 1)}{2}({\sigma_s}^2 - {\sigma'_{87}}^2) \,. \tag{1.21}$$

The term on the left hand side of the above equation, $\ln\left(\frac{i_t}{p_t y_t} / \frac{i'_{87}}{p'_{87} y'_{87}}\right)$, was regressed on $\ln \frac{\bar{p}_s}{\bar{p}'_{87}}$ and ${\sigma_s}^2 - {\sigma'_{87}}^2$. It was assumed that the regression errors were independently, identically, and normally distributed, and the rates were estimated with the method of maximum likelihood. The null hypothesis of the rate being smaller than unity was tested against the alternative hypothesis of the rate being equal to or larger than unity. Congo, Gabon, Gambia, Mauritania, Seychelles, Jamaica, Hong Kong, Jordan, Malaysia, Belgium, Malta, the Netherlands, and Papua New Guinea did not reject the null hypothesis at the significance level of 10%. Mauritius, Guyana, Singapore, Cyprus, and Ireland rejected at the significance level of 10%. Cape Verde and Singapore did not reject the null hypothesis at the significance level of 5%, but at the level of 10%. Table 1.2 summarizes the results.

The relative-risk-aversion rate has been intensively examined with the use of capital asset pricing models and US financial data. Restricting our attention to models with constant-relative-risk-aversion utilities, we find typical values for the rate to be around 4 (Grossman and Shiller, 1981), and smaller than 1 (Hansen and Singleton, 1982, 1983). The elasticities of intertemporal substitution in consumption in developing countries were investigated by Giovannini (1985). He found the values to be very low, implying high rates of relative-risk-aversion for countries other than the US. This essay differs from the previous works on

[18] The available terms-of-trade data had been normalized with values from 1987 as the base year data by the World Bank (1993). Thus, estimations using such data required normalization of regression equations, and the data from 1987 was excluded from estimation. In principle, any of Equations (1.15), (1.16), (1.17), and (1.18) can be employed for the estimation. The equation for consumption level was not used, as it cannot be solved explicitly for α. The growth equations were not used as they are required for growth-rate evaluation.

Table 1.2: Maximum Likelihood Estimates for Relative-Risk-Aversion Rate (α)

Country	α Estimate	α (Standard Error)	Rank
Cape Verde	1.65	(0.41)	5
Congo	0.78	(0.31)	2
Gabon	2.18	(1.02)	6
Gambia	6.02	(4.48)	9
Mauritania	5.36	(6.70)	7
Mauritius	28.01	(7.36)	16
Seychelles	6.63	(4.55)	10
Barbados	12.86	(10.96)	12
Jamaica	0.59	(0.21)	1
Guyana	186.14	(71.27)	19
Hong Kong	14.41	(15.33)	14
Jordan	6.85	(8.11)	11
Malaysia	677.79	(899.96)	20
Singapore	38.46	(27.57)	18
Belgium	1.39	(0.35)	4
Cyprus	33.91	(16.86)	17
Ireland	13.60	(6.26)	13
Malta	5.69	(9.09)	8
Netherlands	0.81	(0.12)	3
Papua New Guinea	20.37	(82.64)	15

risk-aversion-rates in its explicit consideration of production. Our model regards investment in production as an activity influenced by uncertainty, as the representative agent does not know the worth of the investment in terms of consumption goods, which are all imported and thus are subject to precarious terms-of-trade. Our model produced estimated rates ranging from Jamaica's 0.6 to Malaysia's 680. Large estimates (such as Papua New Guinea's 20, Cyprus' 34, Singapore's 38, Guyana's 190, and Malaysia's 680) tended to be associated with large standard errors; the smaller estimates were more reliable. There appeared to be no regional factor in the ordering of the countries based on the magnitude of the rate.

Simulation of Growth Rates Implied by Model

The purpose of growth rates simulation (using the growth equations derived earlier in the Model section) is to show how well terms-of-trade explains changes in the growth rates of output per capita, investment per capita, and consumption per capita. The parameter values necessary for simulation in real-business-cycle models (e.g. real interest rate) are usually obtained from other empirical studies. In the model presented in this essay, there is only one such parameter, i.e. relative-risk-aversion rate, since the simulation procedure requires normalization of growth equations. As direct measurements of the risk aversion rates for the countries of interest were not available, their estimates based on the investment level equation from the model were used for growth rate simulation. That is, the equation for parameter estimation (Equation (1.21)) and that for growth rate simulation (which uses the parameter estimates) are both obtained from the same model. However, since the parameter estimation does not rely on the growth rate of investment nor on that of output, our simulation of the growth rates is not equivalent to confirmation of the parameter values obtained earlier.

The expected value of terms-of-trade, which appears in the equations specifying the optimal path, i.e. $E_t({p_{t+1}}^{1-\alpha})$, must be known for simulation purposes. This means that we need an assumption that explicitly specifies how expectations are formed. We assume that the representative agent regards the logarithm of terms-of-trade as a Gaussian process with structural breaks.

Equations (1.17) and (1.18) were normalized as follows:

$$\frac{i_t/i_{t-1}}{i_{'87}/i_{'86}} = \left(\frac{\bar{p}_s}{\bar{p}_{'87}}\right)^{\frac{1-\alpha}{\alpha}} e^{(\alpha-1)(\sigma_s^2-\sigma_{'87}^2)/2}\frac{p_t}{p_{'87}},$$

$$\frac{y_{t+1}/y_t}{y_{'88}/y_{'87}} = \left(\frac{\bar{p}_s}{\bar{p}_{'87}}\right)^{\frac{1-\alpha}{\alpha}} e^{(\alpha-1)(\sigma_s^2-\sigma_{'87}^2)/2}\frac{p_t}{p_{'87}}.$$

Using the above equations, the obtained estimates for α, the actual growth rate values for $t = 1971$, and investment and output growths were calculated for each of the twenty countries. The growth rate of consumption was calculated using the predicted output and investment levels and the relationship $p_t y_t = c_t + i_t$. The tables in Appendix B provide the summary statistics (the mean, the standard deviation, correlation between the actual and the simulated rates, etc.). The figures in Appendix C compare the actual and the simulated growth rates for each country.

Observations and Implications

Stylized Facts of Business Cycles

The actual growth rates of per-capita output were positively correlated with those of investment (except for Mauritania and Barbados) and of consumption (except for Gabon), according to the tables in Appendix B. That was also the case for corresponding simulated values for all countries (including Gabon, Mauritania, and Barbados) excepting Seychelles.

The orderings of various standard deviations of the actually observed growth rates did not match very well with their simulated counterparts. The standard deviations of actual $\Delta \ln i$ were about 2 to 5 times as large as those of actual $\Delta \ln y$. However, the standard deviations of the simulated values were about the same for all countries.[19] The standard deviations of actual $\Delta \ln c$ were larger than those of actual $\Delta \ln y$ (except for Singapore, Belgium, Cyprus, and the Netherlands). The standard deviations of simulated $\Delta \ln c$ and simulated $\Delta \ln y$ were about the same, while those of simulated $\Delta \ln c$ were smaller than those of simulated $\Delta \ln y$ for Cape Verde, Mauritania, Malaysia, Belgium, Cyprus, and the Netherlands.

In sum, the actually observed growth rates of almost all countries showed patterns similar to some of the stylized facts of US business cycles, such as (i) consumption and investment are procyclical, and (ii) investment is more volatile than output. The model reproduced the correlations among the growth rates well, but not the standard deviations of the growth rates.

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[19] This is due to the assumption of the AK technology and complete depreciation of capital in each period.

Comparison of Actually Observed and Simulated Growth Rates

An inspection of the standard deviations (in Appendix B) reveals that those for actual $\Delta \ln y$ are smaller than or roughly equal to those simulated (except for Gambia and Cyprus).[20] In contrast, the standard deviations for actual $\Delta \ln i$ are larger than those for the simulated counterparts (except for Cape Verde, Congo, and the Netherlands). Consumption growth that is smoother than the one predicted by the model is seen in all countries except Gambia (whose per-capita consumption sometimes exceeded per-capita output), Mauritania, Jordan, and Cyprus.

Roughly speaking, the actual and the corresponding simulated correlation coefficients between various growth rates tended to be closer to each other for the countries with small estimates of relative-risk-aversion rate. Looking at the data pertaining to the countries with an estimated relative-risk-averion rate smaller than 5 (Cape Verde, Congo, Gabon, Jamaica, Belgium, and the Netherlands), we see that the correlation coefficients between actual per-capita output and per-capita consumption growths and those between their simulated counterparts tend to show good correspondence. The correlations based on the simulated values are within a 15% range of that based on the actually observed values for Cape Verde, Congo, Jamaica, and Belgium. Gabon and the Netherlands have estimated rates smaller than 5, but fail to fall in the 15% range.[21] The actual and simulated correlations between per-capita output and per-capita investment growth show good correspondence in the above sense for Congo, Gabon, Belgium, Ireland, and the Netherlands.

[20] The countries whose two standard deviations of output growth rates showed about the same values were Jordan and Singapore.

[21] Gabon's case may be due to its negative correlation between the actual output and consumption growth rates. Another exception is Guyana, whose estimated rate is larger, but its actually observed and simulated values were close to each other.

Terms-of-Trade Change as Productivity Shock

As was mentioned earlier, international trade constitutes a large portion of economic activities in the economies investigated in this essay. Thus, the oil shocks were expected to leave significant marks in output growth rate. However, the output growth rate did not fluctuate as much as the model implied. This may be because of some inertial aspects of the actual economy ignored by the model. We have assumed complete capital depreciation, and such an assumption of flexibility may be a cause for the model-economy's overreaction compared to the actual economy.

Unfortunately, the simulated growth rates miss the magnitude as well as the timing of changes in the actual growth rates. The overall discrepancy between the actual and simulated rates may be attributable to the fact that all terms-of-trade shocks are considered identical in nature, while they could well be qualitatively different in their actual impacts on the economy. This point may also apply to technology shocks. That is, each shock jolts the economy in a different manner, and the difference is such that it cannot be ignored in macroeconomic considerations. After all, the impacts of an oil shock and a sudden increase in the price of coffee must have been different, as must have been those of the success in mass production of insulin and the invention of the microchip. Neither the treatment of technology shocks in conventional real business-cycle models, nor that of terms-of-trade in this essay, takes such diversity in productivity shocks into account. Nonetheless, the previous models have been successful in replicating the actual growth rates of various variables when technology shocks are calculated from Solow residuals (Plosser, 1989; Cardia, 1991). According to Cardia (1991), productivity shocks were much more powerful than monetary and fiscal shocks in reproducing the statistical characteristics of the actual economic variables. In addition, the high persistence of productivity shocks has been identified as *sine qua non* in reproduction of empirical regularities (Cardia, 1991; Correia, Neves, and Rebelo, 1995). However, terms-of-trade changes acted as highly persistent productivity shocks and yet did not explain the actual economy well.

What appears crucial in mimicking real economies is the high correlation between output and productivity shocks. The correlation coefficient between Solow residual and output has been reported to be high: around 0.8 for both the US and Germany (Cardia, 1991). Unlike the Solow residual, the growth rate of terms-of-trade was not correlated with that of output per capita. For most countries (as shown in Appendix B), the correlation coefficient was less than 0.3, while the highest values were 0.4 for Mauritius and 0.6 for Malaysia. In short, the Solow residual as the measurement of technology shocks is highly persistent and highly correlated with the growth rate of output (Mankiw, 1989; Cardia, 1991), while terms-of-trade in this essay is also persistent, but not highly correlated with output. Therefore, it may be that the success of replication is linked to the high correlation between productivity shock and output growth, rather than to shock persistence.

Conclusions

We have considered a small, open economy that completely specializes in the production of one export commodity and imports all goods for consumption and investment. We have investigated the long- and the short-run effects of uncertain terms-of-trade, i.e. effects on economic growth and business cycles. We built a neoclassical economic growth model for that purpose. The short-run analyses were based on the fact that terms-of-trade changes are analogous to directly measurable productivity shocks. International capital flows are assumed to be nil. The terms-of-trade data may be represented by various data-generating models, and we adopted the view that the logarithm of terms-of-trade follows normal processes with structural breaks; we leave investigations under other terms-of-trade specifications, e.g. random walk, as research topics for the future. Risk-averse economies react quite differently to increased uncertainty contingent on how averse they are to risks. If the degree of risk aversion is low, the economy will suffer from both retarded growth and decreased utility. If the degree is high enough, the economy saves more and grows at a greater speed, while a greater variance in terms-of-trade reduces utility.

Twenty countries, distinguished by their "openess", were selected for empirical examination. First, the rates of relative-risk-aversion were estimated, using the above specification for terms-of-trade. Subsequently, the growth rates of output per capita, investment per capita, and consumption per capita were simulated, using the estimates and the growth rate equations obtained from the model. The model was successful in reproducing the observed positive correlation between output and investment growths, in addition to another observed positive correlation between output and consumption growths. In actual economies, the standard deviations of investment growth rates were about 2 to 5 times as large as the standard deviations of output growth rates. However, such relationships were not reproduced by the model. The simulated growth rates showed bigger responses to terms-of-trade values than the actually observed ones when there was a pronounced change in terms-of-trade growth. This may be due to inertia in actual economies, which was not accounted for in the model.

In general, discrepancies were observed between the simulated and the actually observed growth rates, in spite of the persistent nature of productivity shocks. There was no clear pattern in the disagreement. One of the possible causes (besides inertia, mentioned above) is that terms-of-trade shocks are not identical in nature, while the model treats them as such. Persistent productivity shocks have been identified as indispensable in explaining the actual behavior of macroeconomic variables. However, Solow residuals interpreted as technology shocks may be capable of explaining business cycles well due to their high correlation with output growth, rather than to their persistence.

CHAPTER II

Use of Industrial Policy and Inter-Industry Knowledge Spillover in Developing Countries

Introduction

This essay examines how an emerging economy benefits from engaging in new industrial activities. More specifically, we explore whether government intervention has the potential to aid successfully economic growth by introducing an industry that operates elsewhere, but not yet in the catching-up economy. We propose that an effective government uses policies aimed at production, as some parts of new technology are obtainable only through production experiences in that industry. One of our claims is that a larger output can be achieved by introduction of a new industry, due to inter-industry knowledge spillover. We also claim that neutrality (with respect to international trade)[1] can be achieved not only under free trade but also under certain combinations of policies. Moreover, we show that, depending on its cause, neutrality has different effects on output.

We note that it is not our attempt to pass judgment on questions of government efforts versus private efforts, such as: "Is the economic environment shaped by the government

[1] Neutrality with respect to international trade (Wade, 1990, p. 55) or absence of trade-regime bias (Krueger, 1984) refers to the situation in which producers are indifferent about selling their products at home or abroad. Hence, neutrality is achieved even when a tariff is imposed, if there is also an appropriate amount of subsidy for the same good that is domestically produced for export.

more growth inducing than that with private sector activities only?" or "Which can carry out an economic agenda more efficiently, the government sector or the private sector?"[2] Our spirit is to consider the government and private sectors as complementing actors in economic growth, not as competing economic entities.

Nor is our inquiry equivalent to the search for an answer to the question: "Are all government interventions beneficial to the economy?" Our investigation is less sweeping; we examine whether the government has the capacity to assist economic growth at all under specific circumstances. It is certainly not our claim that all governments can trailblaze an economic growth path by appropriately choosing the key industry of the time. The focus is on catching-up economies, namely developing countries that attempt to assimilate existing foreign technology. Therefore, the problem of choice of industry is vastly different from that for developed countries, whose attempt it is to pioneer as yet unknown technology and industry. A typical course of development in terms of key industries is well known—starting from light industry, countries proceed to large-scale processing industry (e.g. steel, cement, and petrochemicals), then to capital goods industry, and finally to high-technology industry (Justman and Teubal, 1991)—and many governments of developing economies have made use of this fact. It was the goal of the Ministry of International Trade and Industry of Japan (MITI) to establish heavy and chemical industries when the prevailing comparative advantage was in producing textiles. MITI provided the model for Taiwan and Korea for promoting new industries and technologies (Wade, 1990, p. 326). Although we draw on the recent success of some East Asian countries in our investigation,[3] a government's

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[2] Government failure has been studied quite extensively (for example, Krueger, 1990), as has market failure, and if we wish to answer such questions, we further need to ask: "Can the private sector bring about the same or better benefits than those that the government is capable of delivering?"

[3] Needless to say, many factors, both internal and external, were responsible for the successes of Taiwan, Korea, and Singapore, and those circumstances were not uniform, nor constant over time (Wade, 1990, p. 297-344; Page, 1994). Of all the intertwined elements of these successes, we focus on one of the most important and common features: an economically-enlightened government's use of industrial policies in

providing assistance to fledging enterprises is a well-established practice, in the US as well as elsewhere. The US Small Business Administration was created in 1953 as a part of the Federal Government in order to assist small business concerns, and its numerous programs include those specifically aimed at exporters (US Small Business Administration, 1995).

Our investigation touches upon two important problems in economic development: import substitution and infant-industry protection. We consider a small, open economy, whose production pattern is determined through relative prices as perceived by the private sector. Hence, introduction of new industrial activities in the private sector requires alteration of relative prices that are faced by the producers in that sector. Since the government aims at modification of the economic environment so that the good currently imported will be produced domestically, the investigation is related to the problem of import substitution. The government may modify relative prices by employing a policy which may involve a tax, a subsidy, a tariff, or some combination of these. If such action is taken in order to establish a new industry, it is called infant-industry protection.[4]

It has been pointed out by J. S. Mill (Kemp, 1960) that a tariff can be useful in establishing a new industry, assuming that two conditions are met: (i) the strategy is meant to boost a catching-up economy; and, (ii) technology from abroad must be complemented by local skills and experience before it becomes as efficient domestically as it was abroad. However, the current consensus on the issue of infant-industry protection is essentially the view given by Baldwin (1969). He argued that tackling the market imperfections or externalities directly is more effective in fostering the infant industry than is imposing tariffs in any situation, including that which is considered to justify protection, namely when the

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order to promote new industrial activities, and hence to catch up.

[4] Modification of relative prices does not need to involve trade barriers. However, infant-industry protection is often considered deviation from free trade (a situation in which there exists no obstacle at the border of an importing country).

capital market or appropriability is imperfect (Corden, 1984; Krugman and Obstfeld, 1994, p. 258-259).

The policy of import substitution was advocated by Prebisch and Singer (United Nations, 1949; Singer, 1950) as a way to alleviate developing countries' reliance on primary commodities—whose prices were believed to be subject to continuous deterioration and made importation of manufactured goods difficult—and allow them to industrialize. Their strategy was to protect an infant industry through restricting imports of manufactured goods (Krugman and Obstfeld, 1994, p. 259). Although the current economic difficulties of Latin American countries are often considered legacies of their import substitution strategies, they were compounded by other important problems, such as the absence of necessary accompanying policies, including export stimulation, revenue enhancement, and support for increase in agricultural productivity (Fishlow, 1990). The goal of these countries was to attain self-sufficiency in manufactured goods (Cardoso and Helwege, 1992, p. 84), but to render such goods internationally competitive for the purpose of exportation was not part of the objectives. "[I]mport substitution at any cost" (Balassa, 1980, p. 9) led to overvalued exchange rates and slow export growth (Cardoso and Helwege, 1992, p. 91), and tariffs were considered permanent rather than temporary measures (Balassa, 1980, p. 8-9). The experience of Latin American countries seems to have reinforced the consensus that trade policies should not be employed for the purpose of development.

Despite the widely accepted notion that trade policies are ineffective as infant-industry protection, some of the newly industrializing countries have taken to adopting them (Wade, 1990, p. 358-361). This essay attempts to provide an economic rationale for such intervention, and to close the gap between the existing notion and observations obtained from some East Asian countries. Our rationale hinges on the view that knowledge is not completely tradable and that the nontradable part can be acquired only through experience, and by engaging in production that requires that knowledge (Westphal, 1990). In our framework, therefore, not all the necessary knowledge for efficient production of a good can be obtained by relying on a policy of directly promoting knowledge acquisition. Furthermore, we assume that knowledge spillover occurs across industries. That is, a newly established domestic industry leads to increased productivity in all relevant industries. The issue at hand can be considered a problem of technological externalities, as opposed to pecuniary externalities (Rosenstein-Rodan, 1943; Murphy, Shleifer, and Vishny, 1989), for developing economies.

In order to model the mechanism of inter-industry knowledge spillover, we advance three assumptions. One is that technological information consists of both codified and tacit knowledge, as initially argued by Polanyi (David, 1992). Another is that complete international knowledge transfer is extremely difficult, if not impossible, due to the significance of tacit knowledge. Finally, the missing link in borrowed technology can be recovered only through experiencing production using that technology.[5] Since tacit knowledge of a technology includes perceptions that are commonly shared but rarely made explicit in the originator country, some pieces of information can be transferred internationally only after the product has been taken into production by a catching-up country. The assumptions state that international knowledge spillover has negligible effect. We formulate sector production functions with the above characteristics.

Our model describes a small, open economy in a two-good world.[6] The technology of the economy favors specialization in the production of one good (good 1). The domestic market for good 1 is completely integrated into the world market, which is perfectly competitive and has the capacity to absorb as much as the small economy wishes to sell. Thus, it

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[5] This does not restrict learning to being a function of output. As we argue below, learning can be considered a function of investment in production, which is a constituent of production experience.

[6] We abstract from the issues related to strategic complementarity and selection of target industry, another characteristic of government intervention in East Asia (Pack and Westphal, 1986; Wade, 1990, p. 355).

produces good 1 and sells it in the world market as well as in the domestic market, both at the world price, which is assumed fixed. As is the case for most developing countries, there is no R&D activity. However, production technology may progress due to learning-by-doing and intra- and inter-industry knowledge spillovers.[7] We assume that intra-industry knowledge spillover is immediate and complete, which is consistent with domestic perfect competition.[8] Capital and labor are assumed mobile across industries.[9] Moreover, real exchange rates are stable, and the rest of the world is static.[10] Although the international economy shows no change over time, the government monitors changes in domestic economic conditions continuously, in order to apply appropriate policy tools at all times.[11] There is no international capital flow. In the scenario described above, the government of the small, open economy uses industrial policies in order for prices to allow domestic production of both goods; the government alters the economy's relative prices as perceived by the private sector. For the purpose of focusing on both the effects of industrial policies on economic output, and their economic mechanisms, we assume that the government's overriding objective is long-term economic growth of the country, brought about by a (fairly) effective implementation process.[12] The government does not limit exit or entry of firms, nor does it determine the

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[7] Persistent inter-industry knowledge spillover without R&D implies learning-by-doing in both industries.

[8] By assuming that both of the two industries operate in simple competitive markets, we do not consider special forms of industrial organization such as *chaebol* in Korea.

[9] We abstract from the issue of industries' different capabilities to add value, since we assume perfect competition in both industries (no profit), and perfect factor mobility across industries (equal factor prices in the economy).

[10] The real exchange rates have been quite stable in Taiwan from 1978 to 1987 (Wade, 1990, p. 61) and in Korea from 1970 to 1987 (Wade, 1990, p. 61; Page, 1994).

[11] Government's monitoring of economic conditions (Pack and Westphal, 1986) and government's flexibility in using policy instruments (Wade, 1990, p. 371; Page, 1994) are also important features of East Asian economies.

[12] According to Wade (1990, p. 343), "[m]any other nations have at one time or another tried most of the policy tools used in East Asia. What differentiates their efforts, above all, are a consistent and coordinated attentiveness to the problems and opportunities of particular industries, in the context of a long-term perspective on the economy's evolution, and a state which is hard enough not only to produce sizable effects on the economy but also to control the direction of the effects, which is a more demanding achievement."

allocation of resources. In addition, the government has the capability to impose taxes, pay subsidies, etc., but it balances its budget in each period.[13] As some knowledge necessary for efficient production is acquired only through engagement in production, the government policies are aimed at making production in industry 2 economically feasible. Export of good 2 may be promoted through subsidization.[14]

In a nutshell, the model contains the minimum necessary ingredients to answer the following question: if the comparative advantage of a catching-up economy is such that it specializes in a production of one good, can an attempt by the government to induce more industrial activities result in an increased output through the action of knowledge spillover and learning-by-doing? We show below that some industrial policies may indeed be successful in this regard.

Knowledge Spillover Mechanism

In this section, we derive production functions that take inter-industry spillover into account. We do so by taking a close look at how knowledge that is pertinent to production of goods can be acquired. The resultant production functions are used in the Model section.

Accounting for Knowledge as an Input for Production

Machinery or equipment is most productive when its operator possesses and applies pertinent knowledge. Thus, in addition to the two conventional inputs for production (capital

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[13] During the period of the early 1970's to mid 1980's, the East Asian countries have had small or no government deficits (Korea: World Bank, 1988 and 1994; Singapore: World Bank, 1994; Taiwan: Wade, 1990, p. 60), while Argentina and Mexico had deficits larger than 20% of their current government revenues almost all the time (World Bank, 1988 and 1994). A balanced budget does not leave room for monetization of deficits, which caused macroeconomic instability in Latin American countries (Cardoso and Helwege, 1992, p. 91).

[14] A subsidy is only one of many ways to encourage exportation. Wade (1990, p. 139-158) lists export-processing zones, tariff rebates, nontariff (trade) barriers, export tax incentives, export credits, export cartels, export quality inspection, export marketing, export awards, etc., as the tools used in Taiwan.

and labor) we explicitly consider another input: knowledge. The production function for each sector has the following form:

$$F(K, L, \Theta),$$

where F: production function,

K: amount of capital applied to production,

L: amount of labor applied to production,

Θ: amount of knowledge pertinent to production.

We assert that production per worker in a sector is a function of knowledge per sector-worker when workers are all identical.[15] In addition, if technology shows constant returns-to-scale, then the per-worker production function for industry i can be written as:

$$f_i(k_i, \theta_i),$$

where f_i: production function per-worker in industry i,

k_i: capital per worker in industry i,

θ_i: knowledge per worker in industry i.

Our immediate goal is to obtain an explicit, and as simple as possible, expression for the above production function, one of whose arguments is the amount of knowledge. We do so below by analyzing the process of knowledge acquisition.

Knowledge Acquisition

Knowledge can be sought actively and acquired through allocating resources to R&D, or it can be acquired spontaneously through the process of learning-by-doing or knowledge

[15] Suppose, contrary to the assertion, that the amount of production per worker is a function of total knowledge available (i.e. the amount of knowledge per worker times the number of workers). Then, more workers engaged in production will result in a higher output per worker through the larger amount of total knowledge. However, each worker having the same piece of information in duplicate (e.g. two copies of the same technical manual) does not bolster per-worker production. Therefore, the production per worker should be a function of amount of knowledge per worker.

spillover.[16] Here we restrict our attention to knowledge that is a by-product of engagement in production (namely, spontaneously acquired knowledge), the more probable case for a developing country.

Learning-by-Doing

Following Arrow (1962), we assume that the amount of knowledge acquired through engagement in production, i.e. through learning-by-doing, can be described as a function of investment. In other words, we assume that learning occurs when production is accompanied by the intention of per-period production increase, and that the replacement of depreciated capital does not contribute to knowledge acquisition. This assumption acknowledges that learning does not occur through a simple repetition of the same production process. When an economic agent is content with the current situation and does not strongly desire to increase the amount of production, the agent engages passively in production or simple-mindedly repeats the process. Such behavior does not contribute to increase in the amount of knowledge and results in an identical amount of production in each period *ceteris paribus*; learning and subsequent application of the obtained knowledge are together a manifestation of desire to improve the situation at hand. Therefore, replacement of depreciated capital, which is meant to maintain the current productive capacity, does not lead to learning. Cumulative output increases even when economic agents are passively engaged (and hence

[16] All knowledge acquisition efforts that require separate allocation of resources will be categorized as R&D. For example, if a researcher at a firm in a developing country identifies technology abroad that can be applied to a product of his/her company, then we consider this R&D, and not knowledge spillover. Note that according to this taxonomy, the effort involved in knowledge acquisition being conscious or unconscious is not what distinguishes knowledge spillover from R&D; technology transfer is a kind of knowledge spillover if the process itself does not involve the explicit use of resources.

Learning-by-doing differs from knowledge spillover in that the economic entities that generate knowledge and that acquire knowledge are identical in the former, while they differ in the latter. This does not mean that knowledge is passed through only one of the processes at a time. Knowledge acquired through learning-by-doing in one industry may be spilled over to another industry.

when there is no increase in the amount of knowledge). Therefore, it is unsuitable as an indicator of knowledge.

Positive net investment in the production process, in contrast, indicates that there is a clear motivation to increase output by increasing the productive capacity; economic agents are actively engaged in production. In sum, learning occurs only when productive activities take place with the aim to increase production, which can be measured by the amount of net investment.[17]

Based on the hypothesis that all technological information consists of codified and tacit knowledge (David, 1992), we claim that tacit knowledge can be obtained only if there is active production experience, which is indicated by the amount of investment in the production process. As asserted in the Introduction, the nontradable information required for efficient production must be obtained through actual engagement in production. When the workers are all identical, knowledge per industry worker obtained through learning-by-doing is a function of net investment per worker in the industry. Hence, knowledge per worker in industry i, gained by time t through learning-by-doing can be written as a function of the amount of per-worker capital in industry i at time t:[18]

$$\theta_i(t) = \zeta(k_i(t)),$$

where $\theta(\cdot)$: knowledge per worker in industry i, gained by learning-by-doing,

$k_i(\cdot)$: amount of capital per worker in industry i.

[17] A question may arise regarding the fate of acquired knowledge when the amount of capital drops below that in the previous period. We assume that some knowledge can be lost. In other words, there is informal and unwritten knowledge that is forgotten unless it is put into practice.

[18] We assume that k_i at time 0 is nil.

Knowledge Spillover

Four kinds of spillovers are distinguishable: domestic intra-industry, domestic inter-industry, international intra-industry, and international inter-industry spillovers. In this analysis, we regard the above ordering of spillovers to be in accordance with their relative significance; domestic intra-industry spillover is the most important, and international inter-industry spillover the least. Since firms in the same industry have many more problems in common with each other than with those in other industries, intra-industry knowledge spillover is assumed to occur much more quickly than spillover across industries. We also assume that knowledge spillover occurs almost exclusively through domestic channels and that domestic intra-industry spillover is immediate and complete.

Domestic spillovers (both intra- and inter-industry) are assumed to be much more significant than international ones for the following reasons. Some foreign technical knowledge is made inaccessible for the sake of national security. Knowledge needs to be transformed before use when crossing national boundaries (for instance, a foreign technology may require an input that cannot be obtained locally, and the scientific literature related to the technology may not be widely available in the local language); it has to be tailored to the local needs. Most critically, tacit knowledge generally cannot be transferred internationally (as mentioned in the Introduction). In sum, international knowledge spillovers are probably negligible compared to their corresponding domestic counterparts. Some knowledge that is part of a production technology, can be obtained internationally, but only through engagement in production.[19]

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[19] A suggestion was made by Arrow (1969) that dissemination of technology is largely governed by personal contacts, and hence the cost of international knowledge transfer is higher than that of domestic. Westphal (1990) claimed that some "circumstantial knowledge" or peculiarity in local conditions constitutes an essential part of technology. He continued that it can be learned only through experience, making complete trading of technology difficult. Teece (1977) summarized the possible difficulties of international technology transfer over those of domestic ones as: distance and communication costs, the latter having become less important. He claimed that communication costs originated from the differences in language, measure-

We now contend that domestic intra-industry knowledge spillover is so significant that it is immediate and complete, even when there is no centralized research effort. In other words, learning-by-doing occurs on an industry-wide scale, as in Stokey (1986). This leads to one of the distinguishing features of our knowledge acquisition mechanism; the focus is on learning-by-doing and domestic inter-industry knowledge spillover. Different knowledge is mined and accumulated by engaging in different productive activities, and industries may benefit from such diversification. Lighting and machine tool industries benefitted from each other's technology during the first industrial revolution (Deane, 1979, p. 99), and so did the firearm, sewing machine, bicycle, and automobile industries in the US during the period of 1840-1910 (Rosenberg, 1976, p. 18). Henry Ford is said to have conceived of the idea of automated car-manufacturing through observing the conveyor belt in a slaughter house (The Economist, 1996). Landes (1969, p. 517) cites the technological interrelatedness in the fields of optics, air transport, photography, xerography, light metals, and nuclear power in postwar Western Europe.[20] Henderson (1994) has shown empirically that domestic inter-industry spillovers do exist in the contemporary US economy. Boldrin and Scheinkman (1988), Succar (1987), and Young (1991) built theoretical models with inter-industry spillovers, but the models lacked a precise specification of the spillover mechanism.[21]

An implicit but crucial assumption has been made in all of the above theoretical studies, namely that there are two kinds of knowledge: one that is general enough to have applications outside the activity for which the knowledge was originally intended, and one

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ment units, engineering standards, culture and attitude, level of economic development, and socioeconomic structure. He showed empirically that the resources required for international transfers of technology are significant, although the costs may vary depending on the manufacturing experience, size, and R&D-to-sales ratio of the transferee firm.

[20] Knowledge acquisition in these fields is more likely to occur via R&D.

[21] All the references cited above involve spillovers as defined earlier, i.e. knowledge sharing without R&D efforts.

that is purely specific to the original activity.[22,23] The kind of knowledge that is relevant to inter-industry spillovers is the first one. This points to an important difference between spillover among industries and that within each industry; inter-industry knowledge spillover relies much more on unsystematic or *ad hoc* communication than intra-industry spillover does. This difference strongly supports our ranking of the four different types of knowledge spillovers.

A Model for Mechanisms of Spontaneous Knowledge Acquisition

The mechanism of knowledge acquisition through learning-by-doing and inter-industry spillover of knowledge is developed below under the assumptions that knowledge is a pure public good (i.e. a non-rival and non-excludable good) and that it is generated as a by-product of production within every industry.[24]

We consider an economy of two industries (industries 1 and 2), each of which produces one type of good. We will consider a pool of knowledge in the economy to which generally applicable knowledge is added and from which knowledge is withdrawn.[25] When a piece of general knowledge is added to the pool by industry 2 and utilized by industry 1, we say that a knowledge spillover from industry 2 to industry 1 has occurred. Knowledge spillovers consist of two phenomena: general knowledge from one industry *entering* the knowledge pool, and its *being utilized* by another industry. Two conditions need to be met

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[22] The first kind of knowledge may be identified as "General Purpose Technology", a term that was proposed by Bresnahan and Trajtenberg (1995). They define such technology to be "characterized by the potential for pervasive use in a wide range of sectors and by their technological dynamism."

[23] There are many ways to classify knowledge. Another useful classification is the separation of knowledge into the part that represents information that is general but needs modification before application to production, and the part that represents information that is required daily to operate machinery and equipment. We may call these two kinds of information *innovative knowledge* and *operational knowledge*, respectively. Note that operational knowledge consists of both general and specific knowledge. This classification illuminates the nature of general knowledge; it may contain both innovative and operational knowledge.

[24] Helpman and Trajtenberg (1994) examined the effects of General Purpose Technologies on economic growth. They treated the technology as exogenous to the model economy for tractability.

[25] The pool is not depleted through a withdrawal, since knowledge is a non-rival good.

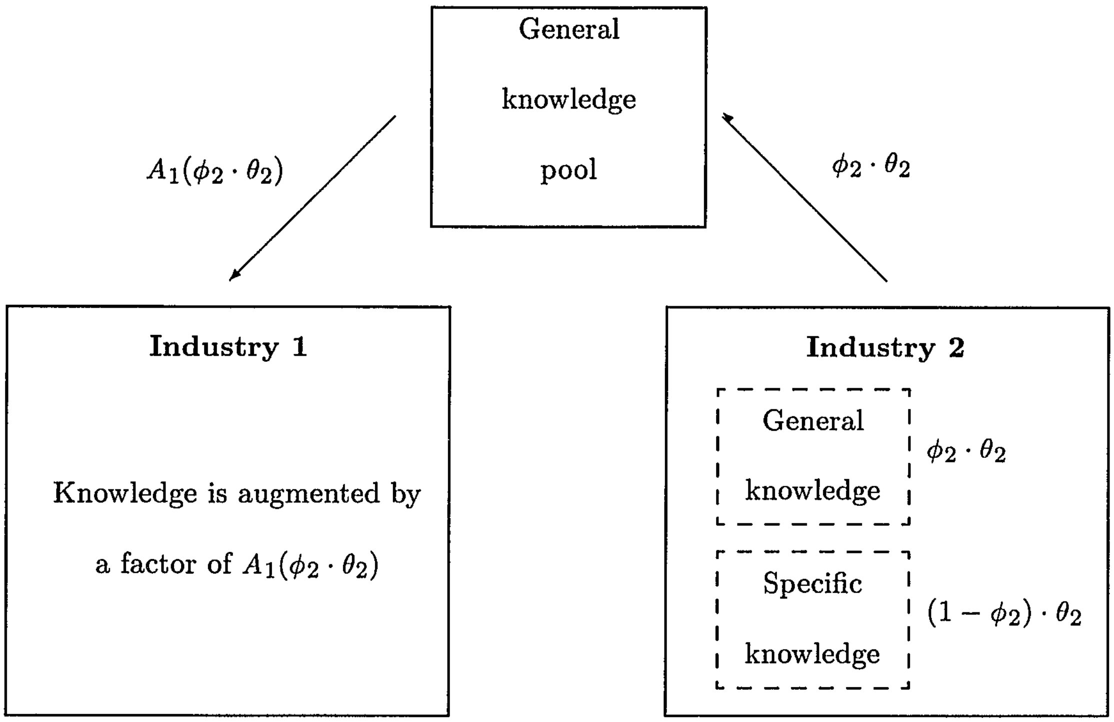

Figure 2.1: Knowledge Spillover from Industry 2 to Industry 1

for knowledge spillovers to take place: entrepreneurs in the recipient industry must pay sufficient attention to and have confidence in the industry that provides the information, and they must also have confidence in the viability of their own industry.

Let us take the example of knowledge spillover from industry 2 to industry 1, as shown in Figure 2.1. We consider a function that converts pooled industry-2 knowledge into a factor by which each unit of industry-1 knowledge is amplified, denoted by $A_1(\cdot)$. Given an amount of general knowledge from industry 2, this function is positively related to industry 1's degree of confidence in itself and industry 1's degree of attention and confidence in industry 2's technology. Suppose that the amount of general knowledge in industry 2 that has the potential to augment per-worker production in industry 1 is $\phi_2 \cdot \theta_2$, where θ is the total knowledge per worker (general and specific), ϕ is the fraction of θ that is general knowledge, and the subscripts indicate the originating industry. Then, the amount of industry-2 knowledge entering the pool is $\phi_2 \cdot \theta_2$. Industry 1 makes use of such knowledge in accordance with its view of itself and industry 2. Therefore, $A_1(\phi_2 \cdot \theta_2)$ is the factor by which general knowledge from industry 2 augments one unit of per-worker knowledge in industry 1. We assume that any knowledge spilled over to industry 1 is absorbed during the same period that knowledge is acquired by industry 2, and *vice versa* (immediacy and completeness of spillover). Further suppose that spilled over knowledge augments per-worker knowledge multiplicatively. Therefore, we may assume that the per-worker production function in industry 1 that incorporates learning-by-doing and knowledge spillover from industry 2 has the form:

$$f_1 = k_1^{a_1} \cdot [\theta_1(k_1) \cdot A_1(\phi_2 \cdot \theta_2(k_2))], \tag{2.1}$$

where $0 < a_1 < 1$ holds and the amount of industry-2 output is positive. Analogously, the per-worker production function in industry 2 that incorporates learning-by-doing and knowledge spillover from industry 1 will have the following form, when industry 1 produces a positive amount of output:[26]

$$f_2 = k_2^{a_2} \cdot [\theta_2(k_2) \cdot A_2(\phi_1 \cdot \theta_1(k_1))], \tag{2.2}$$

where $0 < a_2 < 1$ holds. We assume that the amount of production in an industry is determined solely by its own inputs when it is the only industry in operation; A_1 is equal to unity if and only if the amount of output from industry 2 is equal to zero, and *vice versa.*

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[26] Equations (2.1) and (2.2) are increasing functions of the amounts of capital per industry-worker in both industries. They suggest that decrease in the amount of per-industry-worker capital in industry 2 may decrease the amount of output per industry-worker in industry 1, even when there is no change in the amounts of inputs in industry 1, and *vice versa.* However, restricting our attention to the case of two-sector economies with perfectly-competitive markets, a fixed amount of capital, and perfectly mobile factors, we see that the amounts of capital per industry-worker in the two sectors are positively correlated in equilibrium (cf. p. 47). Therefore, k_2 must be decreasing when k_1 decreases in the above example, and the functional form of the equations does not pose a problem in the discussion below.

The Model

We consider a small, open economy in a two-good world. When there is no government intervention, comparative advantage allows production of only one good (good 1). The domestic and world markets for good 1 are integrated, and the good-1 price will be regarded as the numeraire. The production technology for the second good (good 2) is more capital intensive than that for the first good. When the government does not intervene, the economy does not engage in the production of good 2; it is imported. Our economy is small enough that any amount of goods is available for import at the world price, and any amount can also be exported at the world price. We assume balanced trade and no international capital flow. We employ the production functions formulated in the previous section, without R&D activity, but with learning-by-doing and intra- and inter-industry knowledge spillovers.

The government's interest lies firmly in long-term economic growth, and it keeps a close eye on the economy. The government intervenes to alter the relative price, as perceived by the private sector, through taxes, subsidies on production, and/or tariff policies, so that good 2 is produced at home. It maintains a balanced budget, which consists solely of items related to intervention; tax from industry 1 and tariff on imported goods 2 make up revenue, while subsidy on domestically produced good 2 constitutes expenditure. The policy variables are considered given by the private sector. We assume perfectly competitive markets for both goods and perfect mobility of capital and labor across industries; the government does not attempt to influence the allocation of resources directly.

We develop a model in the environment described above for a representative agent, who is a profit-maximizing producer and also a utility-maximizing consumer. Specifically, we seek an equilibrium with the two industries are in operation. The problem for a representative producer who maximizes profit in the perfectly-competitive first industry is as follows:[27]

$$\max_{k_1, l_1} \quad (1-z)y_1 - w_1 l_1 - r_1 k_1 l_1$$

$$\text{subject to} \qquad f_1(k_1, \theta_1, A_1) l_1 = y_1 = c_1 + x_1 - m_1 \,,$$

where

- k_1: amount of capital per sector-worker in industry 1 (K_1/L_1),
- l_1: proportion of total labor employed for production of good 1 (L_1/L),
- f_1: production function per sector-worker for good 1 (F_1/L_1), determined by k_1, θ_1, and A_1,
- y_1: amount of per-capita production of good 1 (Y_1/L),
- c_1: amount of per-capita consumption of good 1 (C_1/L),
- x_1: amount of per-capita export of good 1 (X_1/L),
- m_1: amount of per-capita import of good 1 (M_1/L),
- z: tax on domestically-produced good 1,
- w_1: wage per sector-worker in industry 1,
- r_1: rental rate of capital-per-sector-worker in industry 1.

The Lagrangian, $\mathcal{L}_{pr1}$, for the above problem is:

$$\mathcal{L}_{pr1} = (1-z) f_1 l_1 - w_1 l_1 - r_1 k_1 l_1 \,.$$

The necessary conditions to be satisfied are:[28]

$$\frac{\partial \mathcal{L}_{pr1}}{\partial k_1} = (1-z)\frac{\partial f_1}{\partial k_1} l_1 - r_1 l_1 = 0 \,,$$

$$\frac{\partial \mathcal{L}_{pr1}}{\partial l_1} = (1-z) f_1 - w_1 - r_1 k_1 = 0 \,.$$

[27] We use upper case letters to denote amounts in the entire economy. Amounts per-capita of the same variables are denoted by corresponding lower case letters (L denotes the total amount of labor).

[28] Since we do not impose positivity constraints on the variables, the first-order conditions hold for non-positive as well as for positive values of them. After obtaining an optimal solution, we confirm the feasibility of the variables.

The above set of equations and the constraint can be reduced to the following three equations:

$$\frac{w_1}{r_1} = \frac{f_1}{\partial f_1/\partial k_1} - k_1\,, \tag{2.3}$$

$$r_1 = (1-z)\frac{\partial f_1}{\partial k_1}\,, \tag{2.4}$$

$$y_1 = f_1 l_1 = c_1 + x_1 - m_1\,. \tag{2.5}$$

In contrast to the producer in industry 1, an industry-2 producer faces domestic *and* world markets, which may have different good-2 prices due to tariff and subsidies; the producers in industry 2 attempt to take advantage of any price difference. Hence, the problem for a representative producer who maximizes profit in the perfectly-competitive industry 2 is:

$$\max_{k_2, l_2, (c_2 - m_2), x_2} \quad (c_2 - m_2)(1+s_d)p_{2,d} + x_2(1+s_w)p_{2,w} - w_2 l_2 - r_2 k_2 l_2$$

$$\text{subject to} \qquad f_2(k_2, \theta_2, A_2) l_2 = c_2 + x_2 - m_2\,,$$

where
- f_2: production function per sector-worker for good 2, determined by k_2, θ_2, and A_2,
- $p_{2,d}$: price of good 2 in domestic market (with good-1 price as numeraire),
- $p_{2,w}$: price of good 2 in world market (with good-1 price as numeraire),
- s_d: subsidy on domestically-produced good 2 for domestic sale,
- s_w: subsidy on domestically-produced good 2 for world market sale.

Other variables are defined analogously to those for industry 1. The Lagrangian, $\mathcal{L}_{pr2}$, for the above problem is given below:

$$\mathcal{L}_{pr2} = (c_2 - m_2)(1+s_d)p_{2,d} + x_2(1+s_w)p_{2,w} - w_2 l_2 - r_2 k_2 l_2 + \mu[c_2 + x_2 - m_2 - f_2 l_2]\,.$$

A solution to the problem must satisfy the following necessary conditions:[29]

$$\frac{\partial \mathcal{L}_{pr2}}{\partial k_2} = -r_2 l_2 - \mu \frac{\partial f_2}{\partial k_2} l_2 = 0\,,$$
$$\frac{\partial \mathcal{L}_{pr2}}{\partial l_2} = -w_2 - r_2 k_2 - \mu = 0\,,$$
$$\frac{\partial \mathcal{L}_{pr2}}{\partial (c_2 - m_2)} = (1 + s_d) p_{2,d} + \mu = 0\,,$$
$$\frac{\partial \mathcal{L}_{pr2}}{\partial x_2} = (1 + s_w) p_{2,w} + \mu = 0\,,$$
$$\frac{\partial \mathcal{L}_{pr2}}{\partial \mu} = c_2 + x_2 - m_2 - f_2 l_2 = 0\,.$$

The above set of equations can be reduced to the following four equations:

$$\frac{w_2}{r_2} = \frac{f_2}{\partial f_2 / \partial k_2} - k_2\,, \tag{2.6}$$
$$r_2 = (1 + s_w) p_{2,w} \frac{\partial f_2}{\partial k_2}\,, \tag{2.7}$$
$$(1 + s_d) p_{2,d} = (1 + s_w) p_{2,w}\,, \tag{2.8}$$
$$f_2 l_2 = c_2 + x_2 - m_2\,. \tag{2.9}$$

A representative agent chooses the amounts to consume of goods 1 and 2 so as to maximize utility, subject to a budget constraint. Assuming that the utility function satisfies the condition, $\partial u / \partial c_{i:\, i \in \{1,2\}} = \infty$ when c_i is equal to zero, $c_{i:\, i \in \{1,2\}}$ must always be positive. The consumer knows that the price of good 1 is the same regardless of its origin, and hence does not treat $c_1 - m_1$ (domestically produced good 1) and m_1 separately. The problem for the consumer takes the following form:

$$\max_{c_1, (c_2 - m_2), m_2} \quad u(c_1, c_2)$$

$$\text{subject to} \qquad y = c_1 + p_{2,d}(c_2 - m_2) + (1 + \tau) p_{2,w} m_2\,,$$

where u: utility of representative consumer,

[29] See Footnote 28.

y: amount of per-capita income,

τ: tariff on imported good 2.

The consumer takes the prices as given, and the Lagrangian, $\mathcal{L}_c$, for the consumer's problem is:

$$\mathcal{L}_c = u(c_1, c_2) + \lambda[c_1 + p_{2,d}(c_2 - m_2) + (1+\tau)p_{2,w}m_2 - y]\,. \tag{2.10}$$

The optimal values for c_1, c_2, and m_2 need to satisfy the following first-order necessary conditions:

$$\frac{\partial \mathcal{L}_c}{\partial c_1} = \frac{\partial u}{\partial c_1} + \lambda = 0\,, \tag{2.11}$$

$$\frac{\partial \mathcal{L}_c}{\partial (c_2 - m_2)} = \frac{\partial u}{\partial c_2} + \lambda p_{2,d} = 0\,, \tag{2.12}$$

$$\frac{\partial \mathcal{L}_c}{\partial m_2} = \lambda[-p_{2,d} + (1+\tau)p_{2,w}] = 0\,, \tag{2.13}$$

$$\frac{\partial \mathcal{L}_c}{\partial \lambda} = c_1 + p_{2,d}(c_2 - m_2) - y = 0\,. \tag{2.14}$$

Since labor and capital are perfectly mobile across industries, the wages and the rental prices of capital must be uniform in the economy. Hence, Equations (2.3), (2.4), (2.6), and (2.7) can be rewritten as follows:

$$\left(f_1 - k_1\frac{\partial f_1}{\partial k_1}\right) \Big/ \frac{\partial f_1}{\partial k_1} = \left(f_2 - k_2\frac{\partial f_2}{\partial k_2}\right) \Big/ \frac{\partial f_2}{\partial k_2}\,, \tag{2.15}$$

$$(1-z)\frac{\partial f_1}{\partial k_1} = (1+s_w)p_{2,w}\frac{\partial f_2}{\partial k_2}\,. \tag{2.16}$$

All the available resources are exhausted by the two industries, and hence the equations below hold:

$$0 < l_{i:\, i\in\{1,2\}} < 1\,,\;\; l_1 + l_2 = 1\,, \tag{2.17}$$

$$k_{i:\, i\in\{1,2\}} > 0\,,\;\; k_1 l_1 + k_2 l_2 = k\,, \tag{2.18}$$

where k is the amount of total per-capita capital, which is assumed to be positive. Moreover, balanced trade implies the following relationship:

$$(x_1 - m_1) + p_{2,w}(x_2 - m_2) = 0\,. \tag{2.19}$$

Therefore, the economy is in equilibrium when Equations (2.5), (2.8), (2.9), and (2.11)-(2.19) hold. Note that when both industries are in operation, Equations (2.17) and (2.18) imply the following:[30]

$$l_1 = \frac{k_2 - k}{k_2 - k_1}, l_2 = \frac{k - k_1}{k_2 - k_1}. \tag{2.20}$$

For the following propositions, we employ the common Cobb-Douglas utility function: $u(c_1, c_2) = \gamma \ln c_1 + (1-\gamma) \ln c_2$, where $0 < \gamma < 1$ holds. Equations (2.11) and (2.12) now imply $\lambda \neq 0$, and thus Equation (2.13) is equivalent to:

$$p_{2,d} = (1+\tau) p_{2,w}. \tag{2.21}$$

Furthermore, Equations (2.11) and (2.12) are reduced to the following expression:

$$(1-\gamma)c_1 - \gamma p_{2,d} c_2 = 0. \tag{2.22}$$

In the production functions derived in the previous section, Equations (2.1) and (2.2), we assume that $\theta_{i:\, i\in\{1,2\}}$ is of the form $k_i^{\eta_i}$ (where $0 < \eta_i < 1$ holds). We further assume that $A_{i:\, i\in\{1,2\}}$ takes the following form for $i \neq j$:

$$\begin{aligned} A_i(\phi_j \cdot \theta_j(k_j)) &= 1 + \xi_i \cdot [\phi_j \cdot \theta_j(k_j)] \\ &= 1 + \xi_i \cdot [\phi_j \cdot k_j^{\eta_j}], \end{aligned}$$

where ξ_i is a positive constant.[31] This form suggests that $A_{i:\, i\in\{1,2\}}$ is always larger than unity, conforming with the view that spilled-over knowledge always works positively on the existing knowledge in the recipient industry. Now we can write the per-capita production function for industry i, when industry j produces a positive amount of output, as follows:

$$f_{i:\, i\in\{1,2\}, i\neq j} = k_i^{a_i} \cdot \theta_i(k_i) \cdot A_i(\phi_j \cdot \theta_j(k_j))$$

[30] Restricting our attention to positive values of $k_{i:\, i\in\{1,2\}}$, the assumption that $0 < \alpha_1 < \alpha_2 < 1$ holds and Equation (2.24) together restrict k_1 to being smaller than k_2. In equilibrium, $l_{i:\, i\in\{1,2\}}$ determined by Equation (2.20) should also satisfy Equation (2.17). Hence, we conclude that $0 < k_1 < k < k_2$ holds.

[31] ξ_i incorporates the level of confidence of industry i in its own future and in industry j's technology.

$$= k_i^{a_i} \cdot [k_i^{\eta_i}] \cdot [1 + \xi_i \cdot \phi_j \cdot k_j^{\eta_j}]$$

$$\equiv k_i^{\alpha_i} \cdot (1 + h_j \cdot k_j^{\eta_j}) , \qquad (2.23)$$

where h_j is a fixed positive constant and $a_i + \eta_i$ is denoted by α_i. For ease of notation, we have absorbed ξ_i and ϕ_j into the constant h_j.

The production function given as (2.23) conforms with the usual assumptions regarding $f_1(k_1, k_2)$ and $f_2(k_1, k_2)$ for two-sector growth models (Uzawa, 1961, 1964; Ryder, 1967; Intriligator, 1971, p. 422): $f_1(0, k_2) = 0$ and $f_2(k_1, 0) = 0$. Furthermore, we assume that the following holds for our model: $f_{i:\, i\in\{1,2\}, i\neq j} = k^{\alpha_i}$, when industry i alone is in operation and output from industry j is equal to zero (cf. p. 40). Finally, we assume that the technologies exhibit diminishing returns to own inputs, i.e. $0 < \alpha_{i:\, i\in\{1,2\}} < 1$ holds. Equation (2.15) can be simplified to:

$$\alpha_2(1 - \alpha_1)k_1 = \alpha_1(1 - \alpha_2)k_2 \, . \qquad (2.24)$$

The government balances its budget, which consists of tax from industry 1, subsidies to industry 2, and possibly a tariff on imported good 2:

$$z f_1 l_1 + \tau p_{2,w} m_2 = s_d p_{2,d}(c_2 - m_2) + s_w p_{2,w} x_2 \, , \qquad (2.25)$$

where the following inequalities hold:

$$s_w \geq 0 \, , \;\; \tau \geq 0 \, , \;\; 0 \leq z < 1 \, . \qquad (2.26)$$

Equations (2.5), (2.8), (2.9), (2.14), (2.16)-(2.22), (2.24)-(2.26), determine an equilibrium when two industries are in operation, and we denote the set of these equations by $\mathcal{S}$.

Our assumption that the economy specializes in the production of good 1 when there is no government intervention (i.e. $\frac{\partial f_1}{\partial k_1} - p_{2,w}\frac{\partial f_2}{\partial k_2} \geq 0$ for all k_1 and k_2 along the production possibility frontier, except when k_1 or k_2 is equal to zero) implies that the domestic price of good 2 will be higher than the world price when the inflow of good 2 is obstructed. We make use of this implication below.

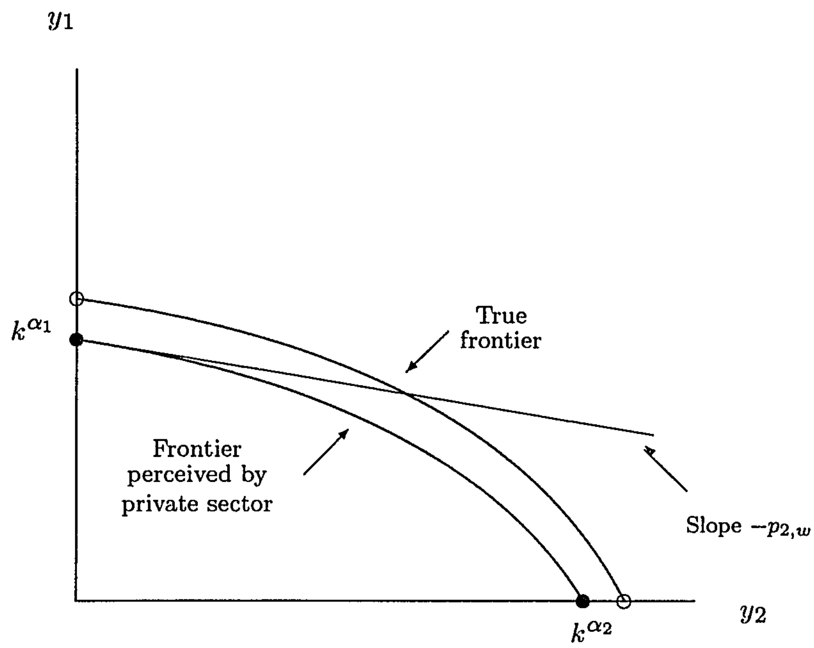

Figure 2.2: Production Possibility Frontiers

Proposition 1 The production possibility frontier as perceived by the private sector is concave (curving downward) when inter-industry knowledge spillover occurs. In addition, the world price of good 2 is smaller than the good-1 price, due to the concavity of the frontier and the relative capital intensity of the two technologies. The true frontier, which takes knowledge spillover into account, lies outside (greater distance from the origin) the frontier as perceived by the private sector.

Proof. (i) Production possibility frontier as perceived by the private sector.

When the government does not intervene, the production technology of our economy and the world price $p_{2,w}$ are such that the economy specializes in the production of good 1; there is no inter-industry knowledge spillover. However, if the world price were such that the economy would engage in production of goods 1 *and* 2, the following equation should hold (Intriligator, 1971, p. 423):

$$\frac{dy_1}{dy_2} = -p_{2,w} = -\frac{\partial f_1/\partial k_1}{\partial f_2/\partial k_2} = -\frac{\alpha_1 f_1/k_1}{\alpha_2 f_2/k_2} < 0\,. \tag{2.27}$$

Note that Equation (2.24) and the inequalities $0 < \alpha_1 < \alpha_2 < 1$ imply $k_2 = \tilde{a}k_1$ (i.e. k_2 is a function of k_1), where $\tilde{a}$ is greater than unity and equal to $\frac{\alpha_2(1-\alpha_1)}{\alpha_1(1-\alpha_2)}$. This relationship and Equations (2.20) and (2.27) lead us to conclude that the frontier is concave:

$$\begin{aligned}\frac{d^2y_1}{dy_2^2} &= -\frac{\alpha_1}{\alpha_2}\frac{d(f_1k_2/f_2k_1)}{dy_2}\\ &= -\frac{\alpha_1}{\alpha_2}\frac{d(f_1k_2/f_2k_1)/dk_1}{dy_2/dk_1}\\ &= -\frac{\alpha_1}{\alpha_2}\frac{d(k_1^{\alpha_1}\cdot\tilde{a}k_1\cdot(\tilde{a}k_1)^{-\alpha_2}\cdot k_1^{-1})/dk_1}{d((\tilde{a}k_1)^{\alpha_2}\cdot(k-k_1)\cdot[(\tilde{a}-1)\cdot k_1]^{-1})/dk_1}\\ &= -\frac{\alpha_1}{\alpha_2}\frac{\tilde{a}^{1-\alpha_2}(\alpha_1-\alpha_2)k_1^{\alpha_1-\alpha_2-1}}{\tilde{a}^{\alpha_2}(\tilde{a}-1)^{-1}[(\alpha_2-1)kk_2^{\alpha_2-2}-\alpha_2k_1^{\alpha_2-1}]} < 0\,.\end{aligned}$$

As the frontier is concave and it includes the (y_1, y_2)-points $(k^{\alpha_1}, 0)$ and $(0, k^{\alpha_2})$, where α_1 is smaller than α_2, we conclude that the slope of the frontier as perceived by the private sector at the good-1 axis is flatter than -1. Considering the fact that the slope of the frontier according to the private sector is $-\frac{\partial f_1/\partial k_1}{\partial f_2/\partial k_2}$, and the assumption that $\frac{\partial f_1}{\partial k_1} - p_{2,w}\frac{\partial f_2}{\partial k_2} \geq 0$ holds for all k_1 and k_2 along the production possibility frontier (excepting $k_1 = 0$ and $k_2 = 0$ points), we see that $p_{2,w}$ is smaller than unity.

(ii) True production possibility frontier.

When inter-industry knowledge spillover is taken into account, we obtain the following under the assumption that $\alpha_2 + \eta_1 < 1$ holds:

$$\begin{aligned}\frac{dy_1}{dy_2} &= \frac{d(f_1l_1)/dk_1}{d(f_2l_2)/dk_2\cdot dk_2/dk_1}\\ &= \frac{(df_1/dk_1)l_1 + (dl_1/dk_1)f_1}{\tilde{a}\cdot(df_2/dk_2)l_2 + \tilde{a}\cdot(dl_2/dk_2)f_2}\\ &= \frac{y_1}{y_2}\cdot\frac{\alpha_1 + \tilde{a}\cdot(h_2\eta_2k_2^{\eta_2})\cdot(1+h_2k_2^{\eta_2})^{-1} + k/(k_2-k)}{\alpha_2 + (h_1\eta_1k_1^{\eta_1})\cdot(1+h_1k_1^{\eta_1})^{-1} - k/(k-k_1)} < 0\,. \qquad (2.28)\end{aligned}$$

Note that when only one industry is in operation, there is no inter-industry knowledge spillover and the frontier perceived by the private sector coincides with the true one. Thus, both frontiers include the two points, (y_1, y_2)-points $(k^{\alpha_1}, 0)$ and $(0, k^{\alpha_2})$; the first point results when all available resources are allocated to industry 1 alone, and the second point when all are allocated to industry 2 alone. However, since Equation (2.24) holds when $l_{i:\,i\in\{1,2\}}$ is greater than zero but smaller than unity, k_i approaches a positive amount when $y_{j:\,j\in\{1,2\},i\neq j}$ approaches zero from the positive side; $y_{i:\,i\in\{1,2\}}$ approaches an amount larger than k^{α_i} when $y_{j:\,j\in\{1,2\},i\neq j}$ approaches zero from the positive side.[32]

Therefore, as Figure 2.2 indicates (see below), the frontier shows discontinuities on the y_i axes. Moreover, our knowledge spillover represents a positive externality (i.e. it is always beneficial to the recipient industry, without depriving the originator industry), causing the frontier with spillover to lie outside the one as perceived by the private sector. Thus, the true frontier consists of the curve further away from the origin, excepting the points on the axes that are indicated by open circles, but including those indicated by solid disks, as shown in Figure 2.2. We note that more information regarding spillover is required in order to identify the precise shape of the frontier; we adopt a concave one without loss of generality for the investigation below. □

Proposition 2 When the government intervenes to alter relative prices as perceived by the private sector, there exists an equilibrium with two industries in operation. It is uniquely determined (up to amounts of net exports) for every nonnegative value of the good-2 tariff τ that is smaller than the subsidy s_w on exported good 2, provided that $\frac{\partial f_1}{\partial k_1} - p_{2,w}\frac{\partial f_2}{\partial k_2} \geq \tau p_{2,w} c_2 \frac{\partial f_2}{\partial k_2} \Big/ f_2 l_2$ holds in equilibrium. However, the condition $\tau < s_w$ requires that the alteration of relative prices not be large (i.e. $p_{2,w}c_2 > f_2 l_2$ must hold) for an equilibrium to exist.

Proof. By combining all the equations in $\mathcal{S}$ except Equations (2.20), (2.24), and Inequalities (2.26), we obtain:

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[32] The actual limiting value of $y_{i:\,i\in\{1,2\}}$ (when $y_{j:\,j\in\{1,2\}}$ approaches zero from the positive side) is dependent on the sizes of h_j and η_j.

$$\left[z + \frac{\tau s_d(1-\gamma)}{\gamma(s_w - \tau) + (1-\gamma)s_d}\right] f_1 l_1$$
$$+ p_{2,w}\left[-s_w + \frac{\tau s_d(1-\gamma)}{\gamma(s_w - \tau) + (1-\gamma)s_d}\right] \frac{1-z}{1+s_w}\frac{\alpha_1}{\alpha_2}\frac{k_2}{k_1} f_2 l_2 = 0\,. \tag{2.29}$$

Substituting Equation (2.20) into (2.29) yields:

$$\left[z + \frac{\tau s_d(1-\gamma)}{\gamma(s_w - \tau) + (1-\gamma)s_d}\right]\left[-s_w + \frac{\tau s_d(1-\gamma)}{\gamma(s_w - \tau) + (1-\gamma)s_d}\right]^{-1}$$
$$\cdot \frac{1+s_w}{1-z}\frac{\alpha_2}{\alpha_1}(k_2 - k)k_1 + (k - k_1)k_2 = 0 \tag{2.30}$$

Further, substituting Equation (2.24) into (2.30), we obtain unique positive values for $k_{i:\, i\in\{1,2\}}$ as functions of exogenous and policy variables. The positivity of the variables is guaranteed from the inequalities $0 \le \tau < s_w$ and $0 \le z < 1$. The unique values of $k_{i:\, i\in\{1,2\}}$ imply unique $l_{i:\, i\in\{1,2\}}$—as functions of exogenous and policy variables.

We turn to Equations (2.5), (2.9), (2.19), and (2.22), which constitute a system with $c_{i:\, i\in\{1,2\}}$, $x_1 - m_1$, $x_2 - m_2$ as unknowns:

$$\begin{pmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & p_{2,w} \\ (1-\gamma) & -\gamma p_{2,d} & 0 & 0 \end{pmatrix}\begin{pmatrix} c_1 \\ c_2 \\ x_1 - m_1 \\ x_2 - m_2 \end{pmatrix} = \begin{pmatrix} f_1 l_1 \\ f_2 l_2 \\ 0 \\ 0 \end{pmatrix}.$$

The matrix of coefficients in the above system has full rank, and hence there exists a unique solution for every right-hand-side column vector. Thus, the four unknowns, as well as y, are also uniquely determined as functions of exogenous variables, policy variables, and $p_{2,d}$. The individual values of $x_{i:\, i\in\{1,2\}}$ and $m_{i:\, i\in\{1,2\}}$ are further restricted by the requirement that m_i be smaller than c_i. Since only net exports of each good are uniquely determined, such conditions can be satisfied with the positive values obtained for c_i.[33]

[33] The expression for c_2 is: $\frac{(1-\gamma)(f_1 l_1 + p_{2,w} f_2 l_2)}{p_{2,w} + \gamma(p_{2,d} - p_{2,w})}$. Since c_2 is positive, so is c_1, which is given as $\frac{\gamma p_{2,d}}{1-\gamma} c_2$.

We now examine whether the above solution is supported by policy variables that are feasible (i.e. which satisfy Inequalities (2.26)). Equation (2.21) shows that $p_{2,d}$ is expressed in terms of an exogenous variable and τ, and τ is nonnegative due to our assumption that $p_{2,d}$ is greater than or equal to $p_{2,w}$. Thus, for every nonnegative value of τ (or $p_{2,d}$), the policy variables can be expressed as follows. We consider Equations (2.8), (2.16), and (2.25) as a system with three unknowns: s_d, s_w, and z. Solving the system, we obtain a unique value for each variable, given τ. Since k_1 and k_2 are positive, nonnegativity of s_w is guaranteed from the expression:

$$s_w = \left[f_2 l_2 \frac{\partial f_1}{\partial k_1} + f_1 l_1 \frac{\partial f_2}{\partial k_2} \right]^{-1} \left[f_1 l_1 \left(\frac{\partial f_1}{\partial k_1} - p_{2,w} \frac{\partial f_2}{\partial k_2} \right) + \tau p_{2,w} c_2 \frac{\partial f_1}{\partial k_1} \right] . \tag{2.31}$$

We also obtain the following expression for z:

$$z = \left[f_2 l_2 \frac{\partial f_1}{\partial k_1} + f_1 l_1 \frac{\partial f_2}{\partial k_2} \right]^{-1} \left[f_2 l_2 \left(\frac{\partial f_1}{\partial k_1} - p_{2,w} \frac{\partial f_2}{\partial k_2} \right) - \tau p_{2,w} c_2 \frac{\partial f_2}{\partial k_2} \right] .$$

Containment of z in the interval $[0, 1)$ is satisfied as long as the following condition is met:

$$\frac{\partial f_1}{\partial k_1} - p_{2,w} \frac{\partial f_2}{\partial k_2} \geq \tau p_{2,w} c_2 \frac{\partial f_2}{\partial k_2} \Big/ f_2 l_2 . \tag{2.32}$$

In addition, Equation (2.31) and Inequality (2.32) imply the following:

$$s_w \geq \tau \frac{p_{2,w} c_2}{f_2 l_2} \tag{2.33}$$

Recalling from Proposition 1 that $p_{2,w}$ is smaller than unity, Inequality (2.33) implies that $f_2 l_2$ should be sufficiently small in comparison with c_2 for $\tau < s_w$ to hold. Since the economy specializes in the production of good 1 under free trade, the above requirement is satisfied when the alteration of relative price is not too large. □

Equation (2.32) is similar to the specialization condition under free trade, i.e. $\frac{\partial f_1}{\partial k_1} - p_{2,w} \frac{\partial f_2}{\partial k_2} \geq 0$: the two are identical when $\tau = 0$, but Equation (2.32) produces a stronger condition when $\tau > 0$. Hence, when intervention does not involve a tariff and if s_w is positive, the economy that specializes in the production of good 1 under free trade will always reach a nontrivial equilibrium under intervention. When a tariff is involved, the condition states that the capital allocation under intervention is determined by a point (along the concave production possibility frontier as perceived by the private sector) that is to the right of the production point under free trade. This is consistent with the nature of our intervention; it brings industry 2, which previously did not exist in the economy, into operation.

Proposition 3 Neutrality (or absence of bias) in trade regime can be achieved in two cases: (a) free trade, and (b) import substitution accompanied by export promotion of good 2.

Proof. Equation (2.8) indicates that the selling prices in the two markets are equal, and thus, that good-2 producers are willing to sell in both domestic and foreign markets. Similarly, Equation (2.21) shows that the good-2 price for consumers is such that they are neutral about the origin of otherwise identical goods 2. In other words, Equations (2.8) and (2.21) guarantee neutrality in trade regime when the economy is in equilibrium.

Equations (2.8) and (2.21) are satisfied in, among others, the following two cases: (a) $s_d = s_w$ and $\tau = 0$ hold, and (b) $0 \leq s_d < s_w$ and $\tau > 0$ hold. Case (a) corresponds to free trade in the sense that no tariff is imposed, and Case (b) to encouraging substitution of the imported good 2 with a domestically-produced one, while also promoting its exportation—by subsidizing the part of good 2 meant for exporting more than that for domestic consumption. □

The above proposition indicates that import substitution and export promotion strategies are not exclusive of one another and that neutrality can be achieved when both strategies are adopted at the same time, as has been asserted by Wade (1990, p. 363).

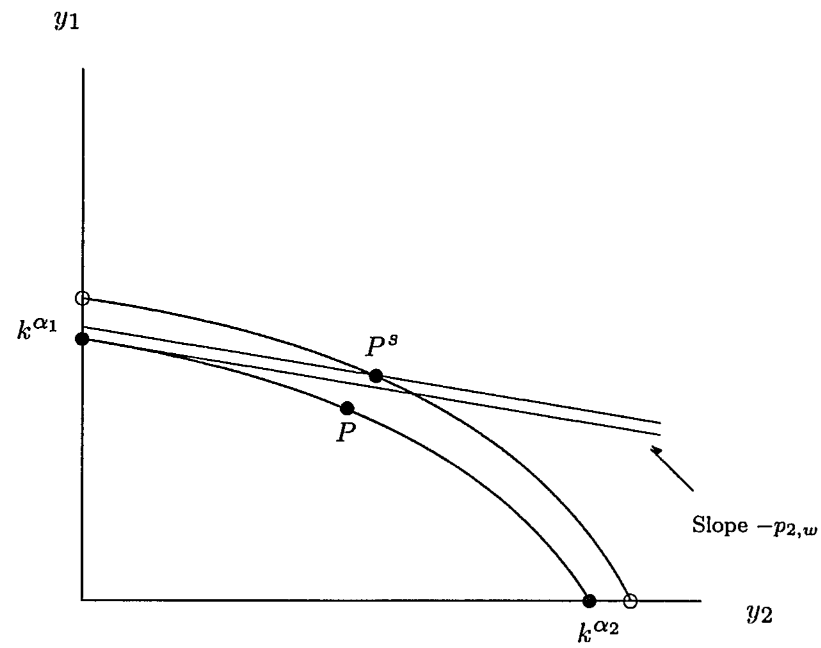

Figure 2.3: Possible Intervention

There is no easy way, if any, to obtain the value of income explicitly in terms of exogenous variables by solving the system of equations defined by S. Hence, we rely on diagrams for further investigation. Note that we will maintain our specification of the utility function in the sequel. That is, the optimal amount of consumption of each good is a linear function of income.

Proposition 4 When the government intervenes to alter relative price as perceived by the private sector and to bring the good-2 industry into operation, welfare is enhanced (and output increased) if the alteration of relative prices is small enough (as in Proposition 2) and if there is enough inter-industry knowledge spillover. However, intervention without a tariff will always result in higher levels of welfare and output than that with a tariff.

Proof. First, we consider a production point under government intervention that shows the amount of production disregarding the additional production gained by inter-industry knowledge spillover. It is obtained as a point where the producer's price line (whose slope is equal to $-(1+s_w)p_{2,w}/(1-z)$) is tangent to the production possibility frontier that does not take spillover into account, such as P in Figure 2.3. If the increase in production due to spillover is taken into account, the production point should be located to the northeast of P (such as P^s, where the superscript s indicates that spillover effects are taken into account).[34]

According to Equation (2.19),[35] the consumption point under intervention must lie on the line which goes through the production point under intervention, but with slope $-p_{2,w}$.[36] Thus, as long as there is enough inter-industry knowledge spillover so that P^s lies outside the consumer's budget set under free trade, increased levels of output and welfare result from intervention.

From Equation (2.10), we see that the following inequality holds:

$$\frac{\partial \mathcal{L}_c}{\partial \tau} = p_{2,w} m_2 \lambda = -p_{2,w} m_2 \frac{\partial u}{\partial c_1} < 0 \,.$$

Application of the Envelope Theorem to the above equation indicates that utility decreases when τ increases. In other words, intervention without tariff is always more welfare enhancing (and results in a higher output) than that with a positive amount of tariff. □

Proposition 4 suggests that a tariff may be useful on economic grounds, while Proposition 2 indicates that the range of tariffs is likely to be small in such a case.

---

[34] Note that the producer's price line is tangent to the frontier that does not take spillover into account, but not necessarily to the frontier that takes spillover into account.

[35] Equation (2.19) can be transformed into $(y_1 - c_1) + p_{2,w}(y_2 - c_2) = 0$, and further into $c_1 + p_{2,w}c_2 = y_1 + p_{2,w}y_2$.

[36] When the consumer choses the optimal consumption point, the prices that matter are the consumer's prices; the consumer's utility curve will be tangent to the consumer's price line, whose slope is $-p_{2,d}$, at the chosen consumption point. Hence, the curve will be also tangent to the line which goes through the production point under intervention (with slope $-p_{2,w}$), but only when τ is equal to zero.

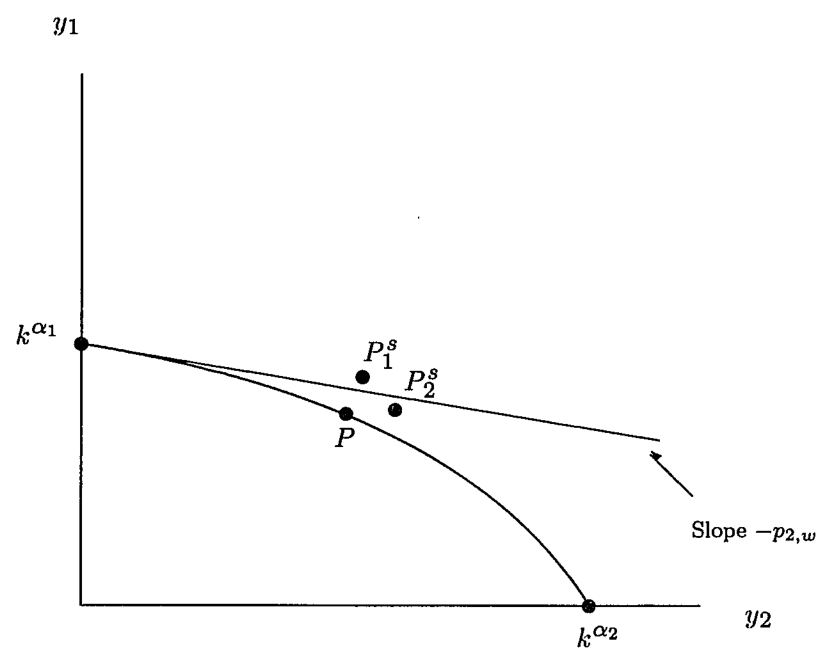

Figure 2.4: Various Effects of Knowledge Spillover

Propositions 3 and 4 together indicate that neutrality in trade regime may be achieved in different ways (import-substitution-*cum*-export-promotion, or free trade), and that how it is achieved matters in its implications for output. Newly industrializing countries in East Asia have effectively used protective measures to establish new industries while promoting exports (Wade, 1990, p. 358-363), and our propositions provide a possible explanation for their success.

Proposition 5 In terms of welfare increase, knowledge spillover from industry 2—the more capital intensive—to industry 1 is more critical than that in the opposite direction (provided that the conditions for the existence of an equilibrium as described in Proposition 2 are met).

Proof. We consider two points that result from identical resource allocation (indicated by point P in Figure 2.4), but from different inter-industry knowledge spillover patterns: P_1^s and P_2^s. Comparing the two points, we see that P_1^s lies outside the consumer's budget

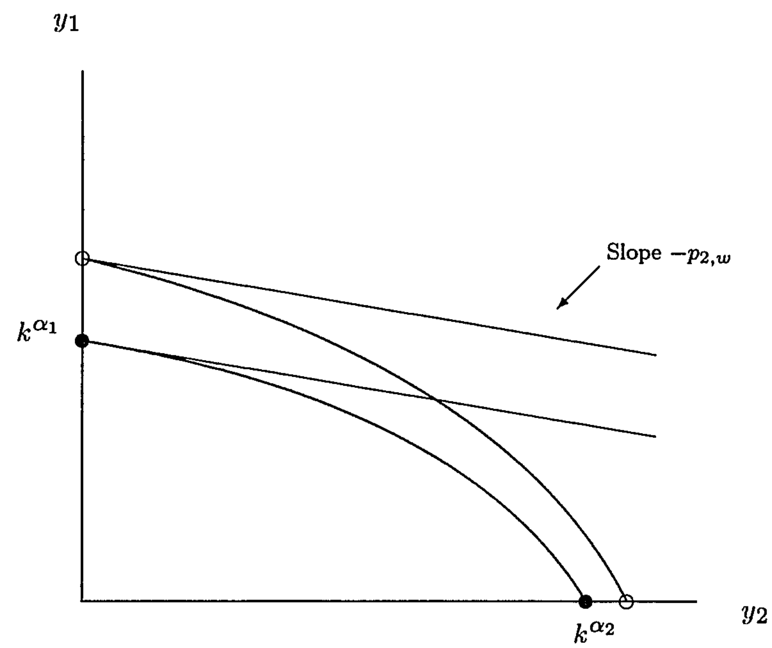

Figure 2.5: Possible Social Optimum

set that corresponds to the no-intervention situation, while P_2^s does not. Note that the consumer's choice must be on the line that goes through the pertinent production point with slope $-p_{2,w}$—regardless of price distortion—as long as the trade is balanced. Hence, P_1^s results in output and welfare that are higher than those when there is no intervention, while P_2^s leads to output and welfare that are lower than those under free trade. We also see that the transition from P to P_1^s involves a larger ratio of movement in the vertical direction over movement in the horizontal direction than that from P to P_2^s, given the total increase in output due to spillover.[37] Hence, for intervention to be welfare enhancing (and to result in a higher output), knowledge spillover from industry 2 to industry 1 has to be more important than spillover in the opposite direction.□

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[37] When the total increase in output that results from spillover is the same for P_1^s and P_2^s, the distance from P to P_1^s should be equal to that from P to P_2^s, as shown in Figure 2.4.

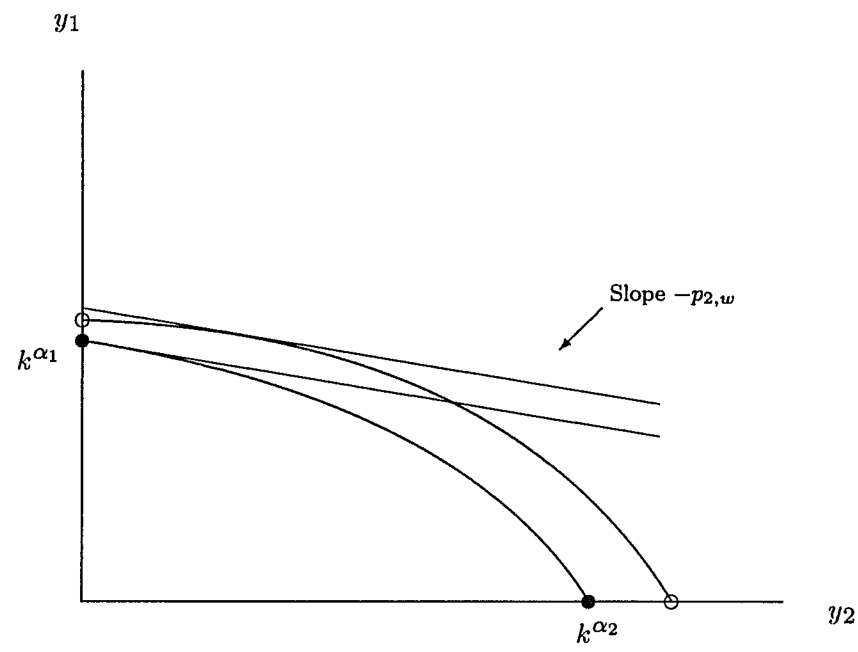

Figure 2.6: Alternative Social Optimum

We now discuss the pattern of production that is socially optimal; a production pattern which is totally coordinated by the government so that the spillover effects are fully taken into account, but without price distortion. In this dicussion, the curvature of the production possibility frontier that takes spillover into account does matter.

Proposition 6 Output from industry 2 is positive but infinitely small at a local social optimum if the production possibility frontier that takes spillover into account is convex. If the frontier is concave, industry 2 may produce a nontrivial amount at the social optimum.

Proof. We note that welfare is unambiguously increased compared to the no-intervention case when there is no price distortion and the allocation of the resources is determined with spillover effects in mind. When the frontier that takes spillover into account is convex, the locally socially-optimal production point is the point on that frontier arbitrarily close to the good-1 axis. Figures 2.5 and 2.6 show that the point arbitrarily close to the good-1 axis or a point with nontrivial output of good 2 may be chosen when the frontier is concave. □

Conclusions

If the comparative advantage of the economy is such that it specializes in production of one good, we find that an attempt by the government to engage in additional industrial activities results in an increased output through intra- and inter-industry knowledge spillover and learning-by-doing. The policies examined ensured a neutral trade regime. We have shown that neutrality under an industrial policy of import substitution and export promotion and that under free trade have different implications for growth.

The following results were obtained upon examination of the problem in a static framework. Government intervention may be welfare enhancing (and lead to higher output) if the tariff on the good whose production the government aims to establish is smaller than the subsidy on exported good produced by the new industry (or if the relative price alteration is not too large). Although a tariff is useful in introducing new industrial activities, it should not be too large for intervention to result in higher welfare. Moreover, intervention without a tariff is more welfare enhancing than that with a tariff. A policy is more likely to succeed if knowledge spillover from the new—more capital intensive—industry to the old one is more significant than that in the other direction.

In conclusion, inter-industry knowledge spillover and learning-by-doing offers an alternative economic reason for catching-up economies' willingness to engage in new industrial activities. The assertion is certainly not that of government's superiority over private initiatives. In our model, the government arranges an economic environment so that private sectors may engage in the production of the second good and the allocation of resources is determined by the market. Our assertion is that the government can assist economic growth by using industrial policies appropriately and that such assistance may involve a tariff.

CHAPTER III

Concessionary Activities in National Parks

Introduction

The main purpose of establishing national parks is to provide the general public with the opportunities to enjoy nature. However, the sheer existence of wondrous nature is usually not sufficient for political and public support, which is essential for park establishment and maintenance (Blower 1984; Dalfelt, 1984). Especially in developing countries, the parks will face difficulties surviving if they do not accept visitors and hence do not contribute directly to the economy (Blower, 1984; Forster, 1973, p. 21). This essay studies the behavior of concessionary firms that provide various services to visitors in a national park, and its effect on nature. The examination makes use of a simple yet insightful categorization of the visitors; the preferences of visitors divide them into two groups (nature oriented and crowd-and-action oriented).

The rationale for this divisioning is as follows. Several studies have shown that people who visit wilderness areas form a heterogeneous group, and that their views vary widely on how the wilderness should be used (Knopp and Tyger, 1973; Lucas, 1964; Schreyer, 1990; Stankey, 1972). Stankey (1972) identified a group of visitors who strongly demanded that the environment not be disturbed by human beings. This group of individuals consistently reported less satisfaction when they experienced encounters with other people in the wilderness, especially motored recreationists, large-sized parties, and anybody near their campsites. Two studies of snowmobilers and cross-country skiers (Jackson and Wong, 1982; Knopp and Tyger, 1973) further showed that the cross-country skiers in their samples were quite consistent in their preferences for other low-impact forms of recreation as well, such as canoeing, backpacking and bicycling. Let us call this group of people who prefer low-impact forms of recreational activities and solitude the *nature oriented.*

One of the studies mentioned above (Jackson and Wong, 1982) also found that the snowmobilers were more interested in socializing, while the cross-country skiers favored solitude and tranquility when engaged in recreational activities. Comparing canoeists and motorboaters, Lucas (1964) found that the canoeists were more demanding regarding how pristine wilderness should be. The motorboaters not only accepted lakes with buildings on their shores as wilderness, but also were more tolerant of intensive recreational use than the canoeists. In addition, motored or high-impact recreation such as snowmobiling generally has a larger negative impact per visitor on ecosystems than recreation that does not involve motored equipment (Hammit and Cole, 1987, p. 180-182). Let us call the group of people who prefer high-impact forms of recreational activities the *crowd-and-action oriented.*

It has been widely recognized that effective wilderness management in recreational areas must be approached from both ecological and nonecological viewpoints (Agee and Johnson, 1988; Geist, 1978). The models in this study make a contribution through bringing together concessionary business, amenity demand, and visitors' impact on nature. They particularly illustrate the size of a chosen species' population with respect to its sustainable yield level when the concessionaires are in operation. Using maximization of sustainable yield as a management goal has been criticized for lack of economic justification and for providing a poor measure of control (Conrad and Clark, 1987, p. 70-71; Ludwig, Hilborn, and Walters, 1993). We show that employing maintenance of the species' population level above the maximum sustainable yield as a goal has a more serious shortcoming; a profit-maximizing monopolist concessionaire may not fulfill such a goal—even when the society consists largely of the nature-oriented kind—depending on the demand characteristics of two groups.

The Model

The features common to the models in this study (models of a monopolist concessionaire and of concessionaires in perfect competition) are as follows. Each model consists of a profit function, which will be maximized by the concessionaires over the period of the contract, subject to the amenity-demand function, the natural-purity equation, the investment-related equation, and the growth function of a biologically renewable resource or critical species. The models can be described concisely in accordance with the typology of Braat and van Lierop (1987). They consist of two interconnected submodels: economic and ecological. The structure of the models is shown in Figure 3.1, with arrows showing influence. The details of each submodel are discussed below.

Economic Mechanism

The concessionary firms in the models operate as follows. They sign contracts to do business in a national park for certain years, and their only concern is the profits they make during that period. When multiple firms operate in the park, they obtain identical contracts at exactly the same time. The contracts are never renewed after expiration, and the concessionaires are perfectly aware of this fact. During the contract years, the concessionaires invest in recreational facilities and supply amenities in the park so as to maximize the sum of the present-valued stream of profits. These profits are defined as the revenue from the visitors' use of facilities and services that the firms provide in the park, net of costs incurred.

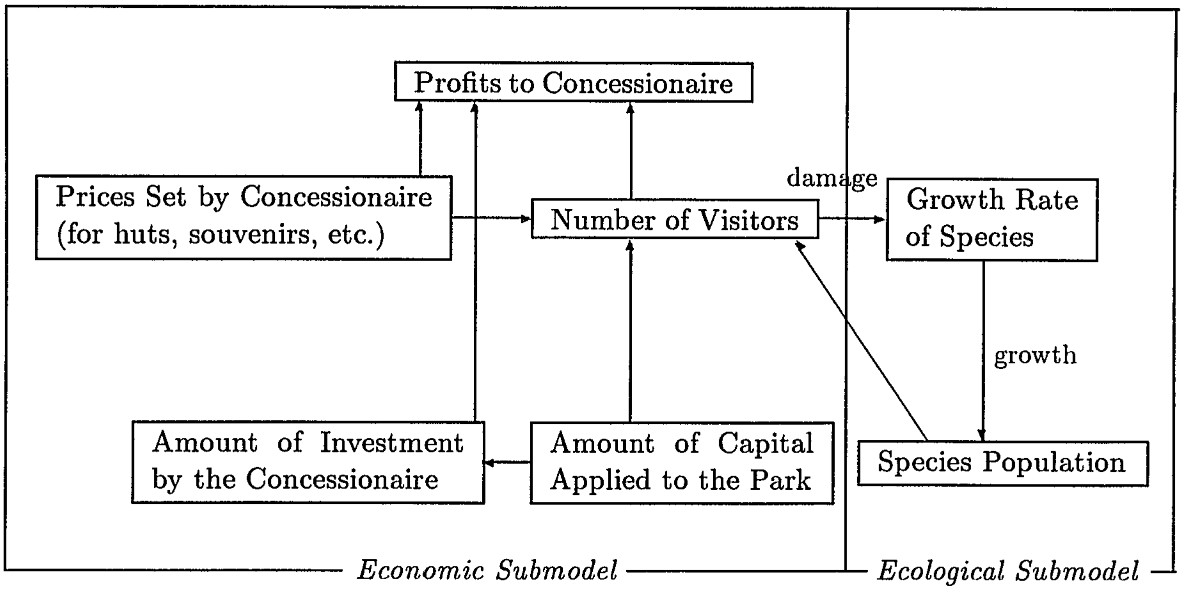

Figure 3.1: Structure of the Models

The costs are those arising from construction of new facilities, maintenance of existing facilities, and payments to the personnel. The costs from construction of new facilities and maintenance of existing facilities are precisely the gross investment costs. The payments to the personnel are considered negligible compared to the gross investment cost, and thus the total cost is wholly expressed in terms of gross investment.[1] The concessionaires' operations will be free of all regulation.

The concessionaires, being endowed with perfect foresight, decide on the amenity supply schedule at the beginning of the contract period. The monopolist concessionaire is free to set prices and the amount of investment. The concessionaires in perfect competition choose only the amount of investment, as the prices are determined by the markets. Price in this study is the average amount of money each person has to spend per unit of time on the goods and services provided in the park in order to engage in preferred activities. There will be a finite upper limit to the total possible investment amount in the park at any time.

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[1] This is equivalent to regarding the fixed cost to be much larger than the variable cost, which is one of the characteristics of businesses in the wilderness (Clawson and Knetsch, 1966, p. 178), or more specifically, of businesses which provide recreational facilities in the wilderness (Binkley and Mendelsohn, 1987).

The visitors are considered to consist of two groups; the nature oriented, who engage in low-impact recreation and seek solitude, and the crowd-and-action oriented, who engage in high-impact recreation and socializing. The first group visits the park only when it possesses more or less undisturbed nature, while the second group visits the park only when there are enough man-made facilities to support their recreational activities.

Ecological Mechanism

To make the problem tractable, some assumptions regarding ecology are in order. A single kind of fauna or flora in the national park is regarded as the critical species. Acknowledging that environmental quality is a multi-dimensional concept and that there is no unique measurement of quality (Mäler and Wyzga, 1976, p. 27), we define the natural purity of the park in terms of two parameters: the population of the biologically-renewable-resource selected as the critical species, and the amount of capital employed in the park.[2]

Our models specify a distinct damage function for each group (the nature oriented and the crowd-and-action oriented), which assesses the damage caused to nature by visitors, and one critical species to represent nature. The growth of the critical species is affected by the damage caused by visitors.[3] The population of the critical flora or fauna, chosen as the measure of natural purity, will be examined. Population ecology of both plants and animals is often described by logistic growth models, and that will also be the case here.

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[2] The outlined natural purity may not be strictly ecologically sound, depending on which species is chosen. Important ecological changes that are not as visible as changes in the population level of a large carnivore or other popular animal or plant often go unnoticed by recreationists (Hammit and Cole, 1987, p. 16). However, what matters in this study is how amenity demand responds to changes in the condition of the park. The precise mechanism through which the employed natural purity reflects the park attribute of our interest is not important for the purpose of this study. As long as the quality represents the degree of attractiveness of the national park in terms of nature, it qualifies as a variable that links the state of nature and the amenity demand.

[3] As visitors' impacts are often local (Hammit and Cole, 1987, p. 22), the damage-causing activities and the chosen species must correspond to the same ecological locus.

The goal is to analyze the population level during the contract periods with respect to its maximum sustainable yield level.

The visitors' demand (the number of visitors in the park at a certain time) is determined by the average amount of money they need to spend per unit of time per person, and by the natural purity. The inclusion of the resource population effect on demands distinguishes the model of this study from conventional biologically renewable resource models. The attraction of the park to the crowd-and-action oriented, which comes from the availability of facilities, will be expressed in terms of natural purity, given a certain pricing level. As the nature oriented individuals are put off when there are too many visitors in the park, their maximum possible number at a time will be considerably smaller than that of the crowd-and-action oriented. Furthermore, the nature oriented take interest only in the basic services the concessionaire offers (e.g. they spend the nights in tents or huts rather than in luxury hotels, they do not buy souvenirs, nor do they go around the park in tour buses).

Generally, the parameters defining environmental quality are interrelated in a complicated way (Mäler and Wyzga, 1976, p. 27). That is certainly the case for our natural purity. The average amount of money necessary to spend a day in the park and the natural purity together determine the number and the kind of people visiting. These in turn determine the amount of damage to the biologically renewable resource of interest. The growth of this resource is slowed down by damage caused by visitors. Finally, the size of the resource population depends on its growth rate, and that size is one of the determinants of natural purity.

Monopolist Concessionaire

Monopolist Model

A monopolist concessionaire acts so as to follow the path directed by the optimization problem below:

$$\max_{P_1,P_2,I} \int_0^T e^{-\delta t}[P_1Q_1 + P_2Q_2 - C(I)]dt \tag{3.1}$$

subject to

$$Q_i = Q_i(P_i(t), q(t)),\ \ (i = 1,2)\,,$$

$$q = q(x(t), K(t))\,,$$

$$\dot{K} = I(t) - \gamma K(t)\,,$$

$$0 \leq I(t) \leq I_{max}\,,$$

$$\dot{x} = F(x) - [D_1(Q_1) + D_2(Q_2)]\,,$$

$$K(0) = K_0 > 0,\ \ x(0) = x_0 > 0\,,$$

where

Group 1:	nature oriented, whose variables are denoted with subscript 1,
Group 2:	crowd-and-action oriented, whose variables are denoted with subscript 2,
$x(t)$:	population of biologically renewable resource at time t,
$K(t)$:	amount of capital in the park at time t,
$q(x(t), K(t))$:	natural purity at time t,
$P_i(t)$:	average amount of money necessary/Group i visitor/unit of time in the park at time t,
$Q_i(P_i, q)$:	total number of Group i visitors in the park at time t,
$I(t)$:	amount of investment in addition to γK_0 at time t,
$C(I(t))$:	cost of $I(t)$,

$F(x(t))$: growth function of biologically renewable resource,

$D_i(Q_i(t))$: damage caused to the biologically renewable resource by Group i visitors at time t,

I_{max} : physical limit to the amount of investment at any time t,

T : duration of contract,

δ : time discount rate,

γ : capital depreciation rate,

$(\dot{})$: time derivative.

The assumptions for the problem are as follows.

Assumption M1: The state variables, $x(t)$ and $K(t)$ are assumed continuous in t, and the control variables, $P_{i:\, i\in\{1,2\}}(t)$ and $I(t)$, are assumed piecewise continuous in t; the optimization is a continuous-time problem.[4] $Q_{i:\, i\in\{1,2\}}$ will be assumed twice continuously differentiable with respect to its arguments. By definition, $Q_{i:\, i\in\{1,2\}}(t)$ and $x(t)$ are nonnegative.

Assumption M2: The concessionaire controls two prices: P_1 for the nature oriented, which is the amount of money needed to pay for basic services (such as spending a night in a tent or hut), and P_2 for the crowd-and-action oriented, which is the amount for nonbasic services (such as spending the night in a motel or a luxury hotel, dining in restaurants, buying souvenirs, etc.). There will be very little overlap in the services the two groups demand, and thus the monopolist sets the two prices independently.[5] The lower the price, the more

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[4] $Q_{i:\, i\in\{1,2\}}(t)$ is determined from $x(t)$, $K(t)$, and $P_i(t)$.

[5] No distinction is made between the amounts of money spent by overnight visitors and day visitors, in order to avoid complication of the model. It is simply assumed that equating Q_i to the average number of visitors from Group i in a 24 hour period (may be fractional) does not excessively distort the true relationship between amenity demand and price. We will assume that the nonnegativity condition on P_i will be met along the optimal path.

members of each group are willing to go to the park, i.e. $\frac{\partial Q_i}{\partial P_i} < 0$ for $i = 1, 2$. Moreover, we assume that the nature oriented people consider their experience in the park unique while the crowd-and-action oriented regard theirs as one of the many possible recreational activities. More specifically, we assume that Group 1 considers price far less important in determining its demand than Group 2 does, leading to the following inequality: $\left|\frac{\partial Q_1}{\partial P_1}\right| < \left|\frac{\partial Q_2}{\partial P_2}\right|$.

Assumption M3: The natural purity, q, is defined solely as a function of the ratio of the population of the biologically renewable resource to the amount of capital in the park, x/K; the bigger the ratio, the higher the natural purity of the park. When the concessionaire commences business, the nature oriented are assumed content with the amount of facilities there are in the park already; any increase in K above the minimum amount with which the concessionaire starts the contract period (denoted by K_0) is undesirable to them.[6] Such amount of facilities attracts so few of the crowd-and-action oriented that initially their number will be considerably smaller than that of the nature oriented. In addition, their demand for park services remains low even after some construction of facilities, regardless of the price charged. Thus, we assume that Q_2 is negligible compared to Q_1 and that Group 2's demand is less sensitive to the amount of facilities than that of Group 1 (i.e. $\left|\frac{\partial Q_1}{\partial K}\right| > \left|\frac{\partial Q_2}{\partial K}\right|$ holds) if K is close enough to K_0.

Assumption M4: The natural purity, q, and the average amount of money necessary/Group i visitor/unit of time in the park, P_i, determine the number of people attracted to the park from each group.

Assumption M5: The higher the natural purity of the park, the more nature oriented people wish to visit, i.e. $\frac{\partial Q_1}{\partial q} > 0$.[7]

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[6] We assume that K_0 is also the amount of facilities a concessionaire needs for business operation.

[7] Considering that q is an increasing function of $\frac{x}{K}$ and hence that the signs of $\frac{\partial Q_i}{\partial q}$ and $\frac{\partial Q_i}{\partial (x/K)}$ are the same,

Assumption M6: The amenity demand by the crowd-and-action oriented is a unimodal function of natural purity. The crowd-and-action oriented group desires a certain amount of facilities in the park. But if there is too little nature left to engage in nature-based recreational activities of their liking as a result of development, they too find limited attraction in the park. Given P_2, such behavior can be expressed as a bell-shaped amenity demand curve with a characteristic level of natural purity, q_{mode}, representing the top of the bell. The relationship between each Q_i and q for given P_i is shown qualitatively in Figure 3.2. We further assume that $\frac{\partial Q_2}{\partial K}$ is positive and that $\frac{\partial Q_2}{\partial x}$ is negative throughout the contract period.[8] In other words, q is always larger than q_{mode}.[9]

Assumption M7: There is a finite amount that the concessionaire is physically able to invest at any time. Moreover, the monopolist maintains the minimum amount of invested capital necessary for business operation, which is K_0; the monopolist invests at least γK_0 at any time to cover the depreciation of K_0. We will regard the amount of investment beyond that minimum amount as bounded between 0 and I_{max} at all times. The cost of maintaining K_0 is at a fixed level throughout the contract period, and $\left.\frac{dC}{dI}\right|_{I=0}$ is equal to that cost.

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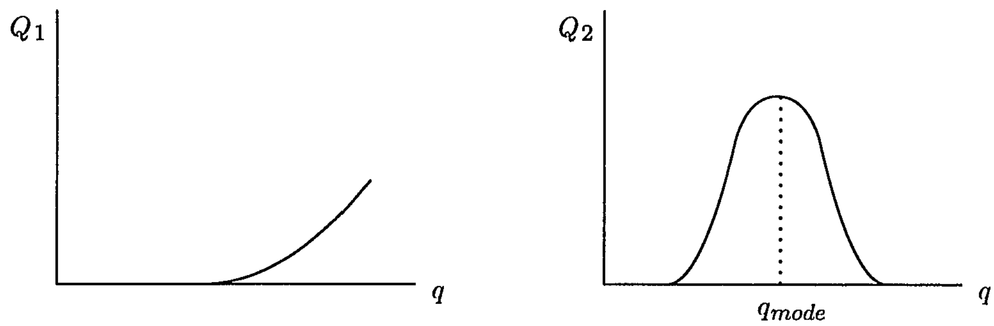
this assumption leads to: $\frac{\partial Q_1}{\partial x} = \frac{\partial Q_1}{\partial(x/K)} \frac{\partial(x/K)}{\partial x} = \frac{\partial Q_1}{\partial(x/K)} \frac{1}{K} > 0$ and $\frac{\partial Q_1}{\partial K} = \frac{\partial Q_1}{\partial(x/K)} \frac{\partial(x/K)}{\partial K} = \frac{\partial Q_1}{\partial(x/K)} \frac{(-x)}{K^2} < 0$, as long as $x > 0$ and $K > 0$. Both inequalities conform with the nature oriented people's assumed behavior.

[8] The reason is as follows. Recall that Q_2 is a unimodal function of q, and hence $\frac{\partial Q_2}{\partial q}$ changes sign at most once during the contract period. Since $sgn[\frac{\partial Q_2}{\partial K}]$ is equal to $sgn[\frac{(-x)}{K^2} \frac{\partial Q_2}{\partial q}]$ when the inequalities $x > 0$ and $K > 0$ hold, $\frac{\partial Q_2}{\partial K}$ also changes sign at most once (from plus to minus) as more facilities are constructed. However, it is unlikely that the concessionaire will keep building facilities beyond even the saturation level, q_{mode}, of the crowd-and-action oriented. Should the monopolist come to face that situation after all, any increase in capital applied to the park will decrease Q_2. If smaller Q_2 is the aim of the concessionaire, the same effect can certainly be achieved by resorting to a price increase, which yields more revenue and costs less than Q_2-control through facilities construction. A situation in which $\frac{\partial Q_2}{\partial K}$ or $\frac{\partial Q_2}{\partial x}$ is equal to zero is unlikely to be sustained, excepting when Q_2 is zero; the crowd-and-action oriented will respond to an increase or decrease in the amount of facilities or in the biological population, other things being equal, when they are interested in visiting the park at all. Therefore, $\frac{\partial Q_2}{\partial K}$ is positive if $Q_2 > 0$. Since the signs of $\frac{\partial Q_2}{\partial x}$ and $\frac{1}{K} \frac{\partial Q_2}{\partial q}$ are the same and they are opposite to those of $\frac{\partial Q_2}{\partial K}$ and $[-\frac{x}{K^2}] \frac{\partial Q_2}{\partial q}$ $(x > 0, K > 0)$, we also conclude that $\frac{\partial Q_2}{\partial x}$ is negative if $Q_2 > 0$.

[9] *Assumptions M2, M3, M5,* and *M6* lead to the following inequality when K is equal to K_0: $Q_1 \left\{\frac{\partial Q_1}{\partial P_1}\right\}^{-1} \frac{\partial Q_1}{\partial K} + Q_2 \left\{\frac{\partial Q_2}{\partial P_2}\right\}^{-1} \frac{\partial Q_2}{\partial K} > 0$.



(a) Nature Oriented Group (b) Crowd-and-Action Oriented Group

Figure 3.2: Amenity Demand of Two Groups

Assumption M8: We will assume that $\frac{dC}{dI} > 0$ for $I \geq 0$ and that the marginal cost of investment is increasing, i.e. $\frac{d^2C}{dI^2} > 0$. We also assume that the concessionaire is not allowed to take capital out of the park during the contract period.

The optimization problem, (3.1), is to maximize the Hamiltonian at each time t, subject to constraints on I. Thus, the problem is equivalent to:

$$\max_{P_1,P_2,I} e^{-\delta t}[P_1Q_1 + P_2Q_2 - C] + \lambda_1[I - \gamma K] + \lambda_2[F - D_1 - D_2] \tag{3.2}$$

subject to $\quad 0 \leq I(t) \leq I_{max}$.

The Lagrangian for the restated problem is:

$$L = H + \mu_1[I_{max} - I] + \mu_2 I ,$$

where

$$H = e^{-\delta t}[P_1Q_1 + P_2Q_2 - C] + \lambda_1[I - \gamma K] + \lambda_2[F - D_1 - D_2] . \tag{3.3}$$

Under the assumption that H is concave in $(P_1, P_2, Q_1, Q_2, x, K, I)$, the necessary and sufficient conditions for a maximizer are:

$$\dot{K} = \frac{\partial L}{\partial \lambda_1} = I - \gamma K , \tag{3.4}$$

$$\dot{x} = \frac{\partial L}{\partial \lambda_2} = F - D_1 - D_2\,, \tag{3.5}$$

$$\begin{aligned}\dot{\lambda_1} = -\frac{\partial L}{\partial K} &= -e^{-\delta t}\left[\frac{\partial(P_1Q_1)}{\partial K} + \frac{\partial(P_2Q_2)}{\partial K}\right] + \lambda_1\gamma \\ &+ \lambda_2\left[\frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial K} + \frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial K}\right],\end{aligned} \tag{3.6}$$

$$\begin{aligned}\dot{\lambda_2} = -\frac{\partial L}{\partial x} &= -e^{-\delta t}\left[\frac{\partial(P_1Q_1)}{\partial x} + \frac{\partial(P_2Q_2)}{\partial x}\right] \\ &- \lambda_2\left[\frac{\partial F}{\partial x} - \frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial x} - \frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial x}\right],\end{aligned} \tag{3.7}$$

$$\frac{\partial L}{\partial P_i} = e^{-\delta t}\frac{\partial(P_iQ_i)}{\partial P_i} - \lambda_2\frac{dD_i}{dQ_i}\frac{\partial Q_i}{\partial P_i} = 0 \quad (i = 1,2)\,, \tag{3.8}$$

$$\frac{\partial L}{\partial I} = \frac{\partial H}{\partial I} - \mu_1 + \mu_2 = e^{-\delta t}\left[-\frac{dC}{dI}\right] + \lambda_1 - \mu_1 + \mu_2 = 0\,, \tag{3.9}$$

$$K(0) = K_0\,, \tag{3.10}$$

$$x(0) = x_0\,, \tag{3.11}$$

$$\lambda_1(T) = 0\,, \tag{3.12}$$

$$\lambda_2(T) = 0\,, \tag{3.13}$$

$$\mu_1 \geq 0\,, \quad \mu_1[I_{max} - I] = 0\,, \tag{3.14}$$

$$\mu_2 \geq 0\,, \quad \mu_2 I = 0\,. \tag{3.15}$$

These conditions are utilized in the following subsections.

Pattern of Investment in Facilities

Equation (3.6) can be transformed through subtraction of $\lambda_1\gamma$ from both sides, multiplication by the integrating factor $e^{-\gamma t}$, and subsequent integration using Equations (3.8) and (3.12):

$$\begin{aligned}\lambda_1(t) = \int_t^T & e^{-\delta s}e^{-\gamma(s-t)}\left[\frac{\partial(P_1Q_1)}{\partial K} - \frac{\partial(P_1Q_1)}{\partial P_1}\left\{\frac{\partial Q_1}{\partial P_1}\right\}^{-1}\left\{\frac{\partial Q_1}{\partial K}\right\}\right] \\ &+ e^{-\delta s}e^{-\gamma(s-t)}\left[\frac{\partial(P_2Q_2)}{\partial K} - \frac{\partial(P_2Q_2)}{\partial P_2}\left\{\frac{\partial Q_2}{\partial P_2}\right\}^{-1}\left\{\frac{\partial Q_2}{\partial K}\right\}\right] ds\,.\end{aligned} \tag{3.16}$$

There are two ways for the monopolist concessionaire to influence revenue: construction of facilities and change of price. The effect of such actions on revenue from Group i can be expressed as $\frac{\partial(P_iQ_i)}{\partial K}$ and $\frac{\partial(P_iQ_i)}{\partial P_i}$, respectively. Hence, $\frac{\partial(P_iQ_i)}{\partial K}\{\frac{\partial Q_i}{\partial K}\}^{-1} - \frac{\partial(P_iQ_i)}{\partial P_i}\{\frac{\partial Q_i}{\partial P_i}\}^{-1}$ is a comparison between increases in revenue from a unit increase in demand, one brought about by construction of facilities and another by increase in price, both of which concern the same group. Therefore, each amount in square brackets in Equation (3.16) shows how much more revenue per unit-demand would be gained if an identical change in demand were attained through a change in K rather than in P. That is, the concessionary firm compares the effectiveness of the two variables (which are its sole instruments of control) in raising revenue from change in demand. The advantage of building facilities over price change for each group is multiplied by the demand change per unit increase of K. The terms are also time-discounted, taking capital depreciation into account. By adding the two terms, we obtain the time-discounted overall advantage per unit increase of K, manifested in revenue rise. Then, $\lambda_1(t)$ is the sum of the time-discounted stream of advantage in revenue rise from facilities construction over price changes, corrected for capital depreciation.

Note that the biological growth and the damage functions do not appear explicitly in the expression given by Equation (3.16). The monopolist is not interested in the absolute values of revenue increase from facilities construction and price increase, but in comparison of the increases per visitor. The marginal effect on the critical species per visitor is the same, regardless of the means chosen to increase the revenue. Therefore, when the revenue increases per visitor are compared, the growth and the damage functions influence the outcome only indirectly.

From the first-order conditions, Equations (3.9), (3.14), (3.15), and *Assumption M9*, the relationship between investment level and admissible range for $\lambda_1(t)$ can be summarized as follows:[10]

$$\text{Case 1:} \qquad I(t) = 0 \text{ and } \lambda_1(t) < e^{-\delta t}\frac{dC}{dI} = e^{-\delta t}\left.\frac{dC}{dI}\right|_{I=0},$$

$$\text{Case 2:} \qquad I(t) = I_{max} \text{ and } \lambda_1(t) > e^{-\delta t}\frac{dC}{dI} > e^{-\delta t}\left.\frac{dC}{dI}\right|_{I=0},$$

$$\text{Case 3:} \qquad 0 \le I(t) \le I_{max} \text{ and } \lambda_1(t) = e^{-\delta t}\frac{dC}{dI} \ge e^{-\delta t}\left.\frac{dC}{dI}\right|_{I=0}.$$

These can be rewritten as follows:

$$\text{No-Investment Case:} \quad I(t) = 0 \text{ and } \lambda_1(t) \le e^{-\delta t}\left.\frac{dC}{dI}\right|_{I=0}, \tag{3.17}$$

$$\text{Investment Case:} \quad 0 < I(t) \le I_{max} \text{ and } \lambda_1(t) \ge e^{-\delta t}\frac{dC}{dI} > e^{-\delta t}\left.\frac{dC}{dI}\right|_{I=0} > 0. \tag{3.18}$$

Through inspection of the integrand of Equation (3.16) and application of Condition (3.18) we will investigate the pattern of investment. The integrand is rearranged as below for this purpose:

$$-e^{-\delta s}e^{-\gamma(s-t)}Q_1\left\{\frac{\partial Q_1}{\partial P_1}\right\}^{-1}\frac{\partial Q_1}{\partial K} - e^{-\delta s}e^{-\gamma(s-t)}Q_2\left\{\frac{\partial Q_2}{\partial P_2}\right\}^{-1}\frac{\partial Q_2}{\partial K}. \tag{3.19}$$

Under the stated definitions and assumptions,[11] the expression given by Equation (3.19) will initially be negative. We examine two of the simplest cases: Expression (3.19) does not change sign at all, or changes sign at most once as time progresses. In these cases, the integrand will behave qualitatively like either Graph (a) or Graph (b) of Figure 3.3. According to Equation (3.16), the signed shaded area defined by the two axes and the curve is equal to $\lambda_1(t)$.

If the integrand behaves like Graph (a), $\lambda_1(t)$ will be negative throughout the contract period and no investment takes place. In terms of presence in the park, the concessionaire favors the nature oriented over the crowd-and-action oriented. We will now consider two possible cases when the integrand behaves as shown in Graph (b): the advantage of facilities construction over price changes at the beginning of the contract exceeds the cost of initial

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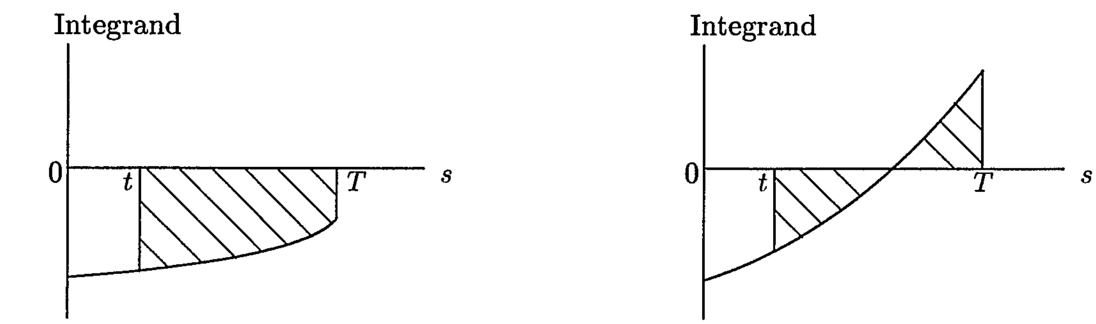
[10] Cases 1, 2, and 3 correspond to ($\mu_1 = 0, \mu_2 > 0$), ($\mu_1 > 0, \mu_2 = 0$), and ($\mu_1 = \mu_2 = 0$) cases, respectively.

[11] See especially Footnote 9.



(a) Integrand does not change sign

(b) Integrand changes sign from minus to plus

Figure 3.3: Possible Relationships between the Costate Variable λ_1 and its Integrand

construction $\left(\text{i.e. } \lambda_1(0) > \left.\frac{dC}{dI}\right|_{I=0}\right)$, or otherwise $\left(\text{i.e. } \lambda_1(0) \leq \left.\frac{dC}{dI}\right|_{I=0}\right)$. In the first case, the inequality, $\lambda_1(t) > \left.\frac{dC}{dI}\right|_{I=0}$, will be satisfied until very close to the end of the contract period and facilities will be constructed continuously. In the second case, Graph (b) indicates that $\lambda_1(t)$ may become greater than $e^{-\delta t} \left.\frac{dC}{dI}\right|_{I=0}$ later during the contract period and stay so until very near the end. Thus, we can conclude that construction will take place, if at all, in the second of three subperiods when construction is initially undesirable compared to price changes (i.e. when $\lambda_1(0) \leq \left.\frac{dC}{dI}\right|_{I=0}$ holds). The three subperiods with respect to investment can be described as follows. The monopolist cashes in on the nature oriented until the park is damaged so much that it is more profitable to attract the crowd-and-action oriented instead. The switching of the target group is attained by building facilities in the second period. No construction is carried out during the last period, since the profits from construction thin out as the contract termination nears.

Under what conditions may the monopolist resort exclusively to price alteration rather than facilities construction? In other words, what makes λ_1 smaller than (a case represented by Graph (a)) or equal to $e^{-\delta t} \left.\frac{dC}{dI}\right|_{I=0}$ (a special case of Graph (b)) throughout the contract period? It is: (i) $e^{-\delta t} \left.\frac{dC}{dI}\right|_{I=0}$ being sufficiently large and/or (ii) the negative Q_1 term always dominating the positive Q_2 term in Expression (3.19).

The first condition is satisfied if the turn-over of facilites is rapid and/or if the maintenance cost of the initial amount of capital is high. When only the nature-oriented may visit, Condition (ii) is certainly met. If both groups are present, it is sufficient for Condition (ii) to be satisfied that the nature-oriented group's demand not be the smaller ($Q_1 \geq Q_2$), and that they be more sensitive to construction of facilities $\left(\left|\frac{\partial Q_1}{\partial K}\right| \geq \left|\frac{\partial Q_2}{\partial K}\right|\right)$, due to the assumption that Group 2 considers price more important in their demand determination than Group 1 does (*Assumption M2*). Put differently, if the demand of the crowd-and-action oriented is sensitive enough to the availability of facilities, construction will take place even when the group is not larger in size.

In summary, there are three possible patterns of investment, depending on the amenity-demand functions and the features of facilities construction as investment. One is not to invest at all, the second is to invest some throughout the contract period except during the very last moments, and the third is to invest only during the second of three subperiods. In other words, the concessionaire may be interested in profiting from either the nature oriented group, the crowd-and-action oriented, or both; the contract will have at most three distinct periods of investment and non-investment. In addition, the demand characteristics of each group may be such that the group with larger demand is less accommodated than the other.

Effects on Critical Species' Population

The strategy for finding the optimum population size for the profit-maximizing concessionaire is as follows. We add an additional constraint, $x \leq x_{msy}$, to the profit maximization problem, (3.1), where x_{msy} denotes the maximum sustainable yield level of the critical species' population. The relationship between the optimal x for the original problem (without the constraint on x), denoted by x^*, and x_{msy} can be inferred from the activeness of the constraint. If the new constraint is active and the corresponding Lagrangian multiplier is positive along the solution path for the modified problem (with the constraint on x), it is an indication that x beyond x_{msy} will yield more profits, and thus that an x^* greater than x_{msy} will be chosen if possible.

This exercise is simplified by switching the roles of x and I in the original problem; x becomes a control variable and I a state variable. The justification for regarding the optimization problem with P_1, P_2, and x as control variables to be equivalent to that with P_1, P_2, and I as control variables is as follows. In Problem (3.1), there are five independent variables (x, K, P_1, P_2, and I) with two equality constraints, and thus the concessionaire has the freedom to set exactly three of the five variables independently. If the problem has a global and unique optimal path, the path must be identical for any choice of the three independent variables as control variables. We will continue to assume that there indeed exists a global and unique optimal path for Problem (3.1).

The modified Lagrangian L^x with the additional constraint is:

$$L^x = H + \mu_1[I_{max} - I] + \mu_2 I + \mu_3[x_{msy} - x]\,,$$

where H is given by Equation (3.3). The modified optimization problem will again have the first-order necessary conditions given by Equations (3.4) to (3.15), excepting Equations (3.7) and (3.9). In addition, the following holds when x is optimal, as L^x will be maximized with respect to x:

$$\frac{\partial L^x}{\partial x} = e^{-\delta t}\left[\frac{\partial(P_1Q_1)}{\partial x} + \frac{\partial(P_2Q_2)}{\partial x}\right] + \lambda_2\left[\frac{\partial F}{\partial x} - \frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial x} - \frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial x}\right] - \mu_3 = 0\,. \quad (3.20)$$

The Lagrangian multiplier μ_3 must satisfy the conditions below:

$$\mu_3 \geq 0\,, \quad \mu_3[x_{msy} - x] = 0\,. \quad (3.21)$$

We can derive the necessary and sufficient condition for μ_3's positivity, or for x^* being larger than x_{msy} when there is no upper constraint on x, from Equations (3.8), (3.20), and (3.21).[12] Since $\frac{\partial F}{\partial x} = 0$ holds when x is equal to x_{msy} for a logistic growth function F, the condition for μ_3's positivity is:

$$e^{-\delta t}\left[\frac{\partial(P_1Q_1)}{\partial x} - \frac{\partial(P_1Q_1)}{\partial P_1}\left\{\frac{\partial Q_1}{\partial P_1}\right\}^{-1}\left\{\frac{\partial Q_1}{\partial x}\right\}\right] + e^{-\delta t}\left[\frac{\partial(P_2Q_2)}{\partial x} - \frac{\partial(P_2Q_2)}{\partial P_2}\left\{\frac{\partial Q_2}{\partial P_2}\right\}^{-1}\left\{\frac{\partial Q_2}{\partial x}\right\}\right] > 0 . \tag{3.22}$$

The interpretation of the necessary and sufficient condition for x^* exceeding x_{msy}, i.e. Inequality (3.22), is as follows. Each amount in square brackets shows how much more time-discounted revenue per unit-demand would be generated if an identical change in demand were attained through a change in x rather than in P. Such an advantage of biological population change over price change for each group is multiplied by the change in demand per unit increase of x. By adding the two terms, we obtain the time-discounted overall rise in revenue per unit increase of x. The assumption that the cost of concessionary activities is a function solely of investment says that the change in revenue is precisely the change in profits in Inequality (3.22). If the overall advantage in profit increase per unit increase of x is positive, concessionary activities will result in an optimal biological population level that is above x_{msy}. Otherwise, the population level may be pushed below x_{msy}. Note that Inequality (3.22) does not explicitly contain the growth and damage functions, as did the expression for λ_1. The reasons for the monopolist's indifference to the functions are the same; the monopolist only wants to know which operation brings about bigger revenue increase per visitor.

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[12] For x^* to be larger than x_{msy}, it is necessary that μ_3 is nonnegative and it is sufficient that μ_3 is positive.

What does the derived necessary and sufficient condition for $x^* > x_{msy}$ imply about the investment in facilities? Transformation of Inequality (3.22) yields:[13]

$$\left[\frac{\partial(P_1Q_1)}{\partial q} - \frac{\partial(P_1Q_1)}{\partial P_1}\left\{\frac{\partial Q_1}{\partial P_1}\right\}^{-1}\frac{\partial Q_1}{\partial q}\right] + \left[\frac{\partial(P_2Q_2)}{\partial q} - \frac{\partial(P_2Q_2)}{\partial P_2}\left\{\frac{\partial Q_2}{\partial P_2}\right\}^{-1}\frac{\partial Q_2}{\partial q}\right] > 0. \tag{3.23}$$

Noting that $\frac{\partial Q_i}{\partial K} = \frac{\partial Q_i}{\partial q}\frac{dq}{d(x/K)}\frac{\partial(x/K)}{\partial K}$ and $\frac{dq}{d(x/K)} > 0$ hold, Inequality (3.23) is equivalent to:

$$\left[\frac{\partial(P_1Q_1)}{\partial K} - \frac{\partial(P_1Q_1)}{\partial P_1}\left\{\frac{\partial Q_1}{\partial P_1}\right\}^{-1}\frac{\partial Q_1}{\partial K}\right] + \left[\frac{\partial(P_2Q_2)}{\partial K} - \frac{\partial(P_2Q_2)}{\partial P_2}\left\{\frac{\partial Q_2}{\partial P_2}\right\}^{-1}\frac{\partial Q_2}{\partial K}\right] < 0. \tag{3.24}$$

The left hand side of Inequality (3.24) is precisely the integrand of $\lambda_1(t)$, given as Equation (3.16), multiplied by $e^{\delta s}e^{\gamma(s-t)}$. Therefore, when $\lambda_1(t)$ is positive it must be that x^* is no greater than x_{msy}. In other words, the population of the critial species cannot be above its maximum sustainable yield level if the concessionaire finds construction of facilities profitable. There is no construction and the population will be above the MSY level if only the nature-oriented may visit (i.e. the integrand of λ_1 stays negative, and hence λ_1 is negative). The population will be above the MSY level also when the nature-oriented are simply more numerous than the crowd-and-action oriented, provided that the former group is more sensitive to the amount of facilities than the latter group (i.e. the integrand of λ_1 stays negative, and hence λ_1 is negative). When neither of the above conditions is met, the species' population may exceed its MSY level only if either the facilities' turn-over is rapid or the maintenance of the initial amount of capital is very costly (i.e. λ_1 is smaller than $e^{-\delta t}\left.\frac{dC}{dI}\right|_{I=0}$, but its nonpositivity is not assured).

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[13] The following relationships were used: $\frac{\partial(P_iQ_i)}{\partial x} = P_i\frac{\partial Q_i}{\partial x}$, $\frac{\partial(P_iQ_i)}{\partial K} = P_i\frac{\partial Q_i}{\partial K}$, and $\frac{\partial Q_i}{\partial x} = \frac{\partial Q_i}{\partial q}\frac{dq}{d(x/K)}\frac{\partial(x/K)}{\partial x}$.

Concessionaires under Other Market Conditions

We now consider concessionary firms under market conditions other than monopolistic: oligopolistic cooperation, and competition that follows from free entry of concessionary firms.

Oligopolistic Cooperation

We consider a situation in which there are n_o (a fixed integer larger than 1) identical firms bound by the same contracts in the park, all of which serve both type of visitors. The otherwise competitive concessionaires cooperate when determining the amount of investment; each invests $1/n_o$ times the total amount, so that the total profits (and hence each concessionaire's profits) are maximized.[14] Moreover, the competition is such that the concessionaires take prices as given. We assume that the conditions for oligopolistic cooperation as described above are achieved through simultaneous entry into the markets at the beginning of the contract.

Since every concessionaire knows that there are $(n_o - 1)$ of others taking the same action at the same time, a concessionaire traces the optimal path of the following problem:

$$\max_{I/n_o} \int_0^T e^{-\delta t} \left[\frac{P_1 Q_1}{n_o} + \frac{P_2 Q_2}{n_o} - C\left(\frac{I}{n_o}\right) \right] dt \,, \tag{3.25}$$

subject to the same constraints as in Problem (3.1), except that $I_{o,max}$, $Q_{o,i0}$, and $K_{o,0}$ are substituted for I_{max}, Q_{i0}, and K_0, respectively. In the above problem, I is the summed amount of investment at time t by all concessionaires in addition to $\gamma K_{o,0}$, and $I_{o,max}$ is the physical limit to the total amount of investment at any time. The assumptions for the oligopolistic-cooperation model are stated below.

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[14] Since each concessionaire's profits are maximized when they cooperate, there is no incentive to deviate from the agreed arrangement; the solution given below is a Nash equilibrium.

Assumption O1: Same as *Assumption M1*, except that the prices are no longer control variables.

Assumption O2: The concessionaires control I only. The two prices, P_1 and P_2, remain independent of each other. The conditions on Q_i, given in *Assumption M2*, hold.

Assumption O3: Same as *Assumption M3*, except that the lower bound on K is $K_{o,0}$, the minimum total amount of facilities the concessionaires collectively need for business operation under oligopolistic cooperation, which is also n_o times the amount with which each concessionaire starts the contract period. The attraction of each group to the park when there is $K_{o,0}$ worth of facilities is such that K_0 is replaced by $K_{o,0}$ in *Assumption M3.*

Assumptions O4 and *O5:* Same as *Assumptions M4* and *M5.*

Assumption O6: The amenity demands are assumed to exhibit the same behavior as in *Assumption M6.* Given P_2, the same level of Q_2 and thus the same amount of revenue can be achieved with two different amounts of capital, where $\frac{\partial Q_2}{\partial K}$ is either positive or negative. Since $\frac{\partial Q_2}{\partial K} < 0$ indicates that less capital leads to lower cost and higher revenue, we assume that $\frac{\partial Q_2}{\partial K}$ is positive and $\frac{\partial Q_2}{\partial x}$ is negative if $Q_2 > 0$, just as in the monopolist case.

Assumption O7: The concessionaires maintain the total minimum amount of invested capital necessary for business operation, which is $K_{o,0}$; each concessionaire invests at least $\frac{1}{n_o}K_{o,0}$ at any time to cover the depreciation of $K_{o,0}$, knowing that the others would do the same. The amount of total investment beyond that minimum amount is between 0 and $I_{o,max}$ at any time t. The cost of maintaining $\frac{1}{n_o}K_{o,0}$ is considered fixed, and is denoted by $\frac{dC(I/n_o)}{d(I/n_o)}\Big|_{I/n_o=0}$.

Assumption O8: Same as *Assumption M8.*

The problem, (3.25), is equivalent to:

$$\max_{I/n_o} \; e^{-\delta t}\left[\frac{P_1Q_1}{n_o}+\frac{P_2Q_2}{n_o}-C\left(\frac{I}{n_o}\right)\right]+\lambda_1[I-\gamma K]+\lambda_2[F-D_1-D_2]$$

$$\text{subject to} \quad 0 \le I(t) \le I_{o,max}\ .$$

The Lagrangian for the problem is:

$$L^o = H^o + \mu_1[I_{o,max} - I] + \mu_2 I\,,$$

where

$$H^o = e^{-\delta t}\left[\frac{P_1Q_1}{n_o}+\frac{P_2Q_2}{n_o}-C\left(\frac{I}{n_o}\right)\right]+\lambda_1[I-\gamma K]+\lambda_2[F-D_1-D_2]\,. \tag{3.26}$$

By assuming that H^o as defined above is concave in $(P_1, P_2, Q_1, Q_2, x, K, I)$, the necessary and sufficient conditions for the optimization problem, (3.2), also hold for the above problem, excepting Equations (3.6)-(3.9). These equations are now replaced by:

$$\begin{aligned}
\dot{\lambda}_1 &= -\frac{\partial L^o}{\partial K} \\
&= -\frac{e^{-\delta t}}{n_o}\left[\frac{\partial(P_1Q_1)}{\partial K}+\frac{\partial(P_2Q_2)}{\partial K}\right]+\lambda_1\gamma+\lambda_2\left[\frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial K}+\frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial K}\right], \\
\dot{\lambda}_2 &= -\frac{\partial L^o}{\partial x} \\
&= -\frac{e^{-\delta t}}{n_o}\left[\frac{\partial(P_1Q_1)}{\partial x}+\frac{\partial(P_2Q_2)}{\partial x}\right]-\lambda_2\left[\frac{\partial F}{\partial x}-\frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial x}-\frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial x}\right], \\
\frac{\partial L^o}{\partial(I/n_o)} &= \frac{\partial H^o}{\partial(I/n_o)} - n_o\mu_1 + n_o\mu_2 = e^{-\delta t}\left[-\frac{dC(I/n_o)}{d(I/n_o)}\right]+n_o\lambda_1-n_o\mu_1+n_o\mu_2=0\,.
\end{aligned} \tag{3.27}$$

The relationship between investment level and λ_1 from the monopolist case (Equations (3.17) and (3.18)) is valid if $\frac{dC}{dI}$ and $\left.\frac{dC}{dI}\right|_{I=0}$ are replaced by $\frac{dC(I/n_o)}{d(I/n_o)}$ and $\left.\frac{dC(I/n_o)}{d(I/n_o)}\right|_{I/n_o=0}$, respectively. The marginal valuation of capital is:

$$\begin{aligned}
\lambda_1 = \int_t^T & e^{-\delta s}e^{-\gamma(s-t)}\left[\frac{1}{n_o}\frac{\partial(P_1Q_1)}{\partial K}-e^{\delta s}\lambda_2\frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial K}\right] \\
&+ e^{-\delta s}e^{-\gamma(s-t)}\left[\frac{1}{n_o}\frac{\partial(P_2Q_2)}{\partial K}-e^{\delta s}\lambda_2\frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial K}\right]ds\,.
\end{aligned}$$

Since Equation (3.27) does not yield an explicit expression for λ_2, we restrict our examination to the species population.

To examine the fate of the critical species, we employ the same strategy as under the previous market conditions. The modified Lagrangian $L^{o,x}$ with the additional constraint, $x \leq x_{msy}$, is:

$$L^{o,x} = H^o + \mu_1[I_{o,max} - I] + \mu_2 I + \mu_3[x_{msy} - x] \, ,$$

where H^o is given by Equation (3.26). The optimization problem will have the first-order necessary conditions (3.4), (3.5), (3.10)-(3.15), (3.21) (3.27), and one additional condition given below.

$$\begin{aligned} \frac{\partial L^{o,x}}{\partial x} = & \frac{e^{-\delta t}}{n_o}\left[\frac{\partial(P_1Q_1)}{\partial x} + \frac{\partial(P_2Q_2)}{\partial x}\right] \\ & + \lambda_2\left[\frac{\partial F}{\partial x} - \frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial x} - \frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial x}\right] - \mu_3 = 0 \, . \end{aligned}$$

Thus, the necessary and sufficient condition for x^*'s being larger than x_{msy} when there is no upper constraint on x is:

$$\left[\frac{\partial(P_1Q_1)}{\partial x} - e^{\delta t}\lambda_2\frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial x}\right] + \left[\frac{\partial(P_2Q_2)}{\partial x} - e^{\delta t}\lambda_2\frac{dD_2}{dQ_2}\frac{\partial Q_2}{\partial x}\right] > 0 \, .$$

This inequality can be rewritten as:

$$\left[\frac{\partial(P_1Q_1)}{\partial K} - e^{\delta t}\lambda_2\frac{dD_1}{dQ_1}\frac{\partial Q_1}{\partial K}\right] + \left[\frac{\partial(P_2Q_2)}{\partial K} - e^{\delta t}\lambda_2\frac{dD_1}{dQ_2}\frac{\partial Q_2}{\partial K}\right] < 0 \, .$$

Analogous to the case of the monopolist, the above expression is precisely the integrand of $\lambda_1(t)$ (for the oligopolistic cooperation case), multiplied by $n_o e^{\delta s} e^{\gamma(s-t)}$. Therefore, the relationship between investment and biological population is the same for the monopolistic and oligopolistic markets; if there is construction of facilities the population of the critical species will not be above the MSY level.

Competition with Free Entry

For sake of completeness, we turn to the case in which concessionaires are allowed to enter the markets freely so as to create a competitive business environment in the park. We continue to assume that every concessionaire operates in both markets. The assumptions are as follows.

Assumptions C1 and *C2:* Same as *Assumptions O1* and *O2.*

Assumption C3, *C4*, and *C5:* Same as *Assumptions M3*, *M4*, and *M5.*

Assumption C6: Same as *Assumption O6.*

Assumption C7: There is no minimum amount of facilities construction that concessionaires carry out in each period. Unlike in the definition of I for the monopolist and oligopolist concessionaires (cf. *Assumptions M7* and *O7*), we denote the amount of all investment that each competitive concessionaire undertakes by I. Any investment is instantly available as facilities for use.

Assumption C8: Same as *Assumption M8.*

Assumption C9: Free entry results in a large number of concessionaires in operation; firms enter the markets until profits for each one of them are driven to zero. Thus, each concessionaire attempts to maximize profits in each time period. Moreover, the share in the revenue for each concessionaire is equal to the share of capital owned by that concessionaire. Since investment is immediately available for use (cf. *Assumpion C7*), we write the share of capital that is invested by each concessionaire as $\frac{I}{K+I}$, where the total amount of capital in the park is denoted by K. Furthermore, we simplify the expression to $\frac{I}{K}$ (where I is infinitesimally small) as there are many concessionaires and I is small compared to K.

The pertinent profit-maximization problem is a static one:

$$\max_{I} \frac{I}{K} \cdot (P_1Q_1 + P_2Q_2) - C(I)$$

subject to $$Q_i = Q_i(P_i(t), q(t)), \; (i = 1, 2),$$

$$q = q(x(t), K(t)).$$

Since I is infinitesimally small, the following Taylor approximation holds:

$$C(I) = C(0) + \left.\frac{dC}{dI}\right|_{I=0} I = \left.\frac{dC}{dI}\right|_{I=0} I,$$

where the cost of no investment is zero (i.e. $C(0) = 0$). Therefore, the zero-profit condition implies the relationship below:

$$\left.\frac{dC}{dI}\right|_{I=0} = \frac{P_1Q_1 + P_2Q_2}{K}.$$

We conclude that the total revenue per unit of capital equals the marginal cost for each concessionaire under competition with free entry. We also note that the detailed behavior of the concessionaires cannot be obtained without further specifications of the functional forms of the variables involved. Compared to the other market conditions which we have investigated, more information regarding characteristics of demand and investment cost is required in order to examine the concessionaires' behavior. This may be phrased as one of the difficulties in park management when the markets are competitive.

Conclusions

The behavior of concessionaires in a national park was investigated in a partial-equilibrium framework. The visitors were grouped into two categories: the nature oriented, who are interested in low-impact forms of recreation and solitude, and the crowd-and-action oriented, who are interested in high-impact recreation (which requires facilities for engagement) and socializing in the park. The purpose of this essay was to construct mathematical models, each consisting of two interdependent submodels, one economic and the other ecological, and to examine the behavior of the concessionaires in the park.

In the models developed in this study, the monopolist and oligopolist concessionaires maximize the time-discounted stream of profits derived from providing services to park visitors, while concessionaires in competitive markets act myopically. Two independent prices, one for each group, and construction of recreational facilities, are decided upon by the monopolist concessionaire. The competing concessionary firms in oligopolistic markets and free-entry markets are price-takers and can decide only on the amount of investment. The cost to the concessionaires is comprised solely of investment. The visitors base their decisions to go to the park on prices and natural purity (determined by the ratio of the population of the critical species in the park to the amount of facilities). The visitors make impacts on nature by negatively affecting the growth of the critical species.

We have focused on facilities construction and the size of the critical species population with respect to its maximum sustainable yield (MSY) level. Construction of facilities is an indication that it is more profitable for the concessionaires to aim for the crowd-and-action oriented than for the nature oriented. Whether the concessionaires choose to engage in facilities building is dependent on amenity-demand functions and on the features of construction as investment (cost of initial capital maintenance, capital depreciation rate, etc.). Under monopolistic and oligopolistic market conditions, the population of the critical species is driven below its MSY level when construction of facilities is undertaken. Therefore, we conclude that profit-maximizing concessionaires in these markets are not capable of attaining two goals simultaneously: keeping the population of the critical species above its MSY level *and* constructing facilities to attract the crowd-and-action oriented. Moreover, if the demand increase of crowd-and-action oriented that accompanies facilities construction is large enough, the monopolist concessionaire will opt for construction, regardless of the size of the nature-oriented group.

APPENDICES

APPENDIX A

Major Trade Commodities

Table A1: Major Trade Commodities

Country	Exports		Imports	
	Value[a]	Commodities	Value[a]	Commodities
Cape Verde	0.0057	fish bananas hides, skins	0.12	foodstuffs consumer goods manufactures transport equipment
Congo	1.1	crude oil lumber plywood coffee cocoa sugar diamonds	0.70	foodstuffs consumer goods intermediate manufactures capital goods
Gabon	1.2	crude oil manganese wood uranium	0.78	foodstuffs chemical products petroleum products construction materials manufactures machinery
Gambia	0.12	peanuts, peanut products fish cotton lint palm kernels	0.15	foodstuffs manufactures raw materials fuel machinery, transport equipment
Mauritania	0.45	iron ore processed fish gum arabic gypsum	0.39	foodstuffs consumer goods petroleum products capital goods
Mauritius	1.2	textiles sugar light manufactures	1.6	manufactures capital goods foodstuffs petroleum products chemicals
Seychelles	0.04	fish copra cinnamon bark petroleum products[b]	0.19	manufactures food tobacco beverages machinery, transport equipment petroleum products

Country	Exports		Imports	
	Value[a]	Commodities	Value[a]	Commodities
Barbados	0.21	sugar, molasses chemicals electrical components clothing rum machinery transport equipment	0.70	foodstuffs consumer durables raw materials machinery crude oil construction materials chemicals
Jamaica	1.0	bauxite alumina sugar bananas	1.8	petroleum machinery food consumer goods construction goods
Guyana	0.19	bauxite sugar gold rice shrimp molasses timber rum	0.24	manufactures machinery food petroleum
Hong Kong	80[c]	clothing textiles, yarn, fabrics footwear electrical appliances watches, clocks toys	80	foodstuffs transport equipment raw materials semimanufactures petroleum
Jordan	0.9	fruits, vegetables phosphates fertilizers	2.1	crude oil textiles capital goods motor vehicles foodstuffs
Malaysia	29	natural rubber palm oil tin timber petroleum electronics light manufactures	27	food crude oil consumer goods intermediate goods capital goods chemicals
Singapore	53[d]	petroleum products rubber electronics manufactured goods	61[e]	capital goods petroleum chemicals manufactures foodstuffs
Belgium[f]	120	iron, steel transport equipment tractors diamonds petroleum products	120	fuels grains chemicals foodstuffs
Cyprus	0.85	citrus potatoes grapes wine cement clothing, shoes	2.3	consumer goods petroleum, lubricants food, feed grains machinery

Country	Exports		Imports	
	Value[a]	Commodities	Value[a]	Commodities
Ireland	25	chemicals data processing equipment industrial machinery live animals animal products	21	food animal feed chemicals petroleum, petroleum products machinery textiles clothing
Malta	1.1	clothing textiles footwear ships	2.0	food petroleum machinery, semimanufactures
The Netherlands	130	agricultural products processed foods, tobacco natural gas chemicals metal products textiles clothing	130	raw materials, semifinished products consumer goods transport equipment crude oil food products
Papua New Guinea	1.3	gold copper ore coffee logs palm oil cocoa lobster	1.6	machinery, transport equipment food fuels chemicals consumer goods

Source: *The World Factbook 1992* and *1993*. Central Intelligence Agency, 1992 and 1993.

[a]Exports and imports are 1990 f.o.b. and c.i.f. values in U.S.$ billion, respectively, unless otherwise noted. Cape Verde: 1990 estimate. Gabon: 1989 value. Gambia: 1990 fiscal year value. Seychelles: 1990 estimate. Guyana: 1990 estimate. Jordan: 1990 estimate. Malaysia: 1990 estimate.

[b]Includes re-exports.

[c]Includes re-exports of U.S.$51 billion.

[d,e]Includes trans-shipments to/from Malaysia.

[f]Begium-Luxembourg Economic Union.

APPENDIX B

Summary of Growth Statistics

Table B1: Cape Verde ($\alpha = 1.65$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.037	0.062	1	0.25
$\Delta \ln c$	0.021	0.093	0.78	0.01
$\Delta \ln i$	0.051	0.149	0.46	0.13
$\Delta \ln (c+i)$	0.031	0.082	0.87	0.09
$\Delta \ln p$	0.030	0.144	0.25	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	-0.243	0.247	1	-0.12	-0.06
$\Delta \ln c$	-0.195	0.144	0.68	0.63	0.04
$\Delta \ln i$	-0.176	0.288	0.68	0.61	-0.17
$\Delta \ln (c+i)$	-0.202	0.278	0.69	0.63	0.05

Table B2: Congo ($\alpha = 0.78$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.020	0.067	1	0.20
$\Delta \ln c$	-0.024	0.149	0.53	0.19
$\Delta \ln i$	-0.076	0.275	0.59	0.25
$\Delta \ln (c+i)$	-0.027	0.148	0.59	0.24
$\Delta \ln p$	-0.048	0.262	0.20	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.124	0.262	1	-0.37	0.28
$\Delta \ln c$	0.107	0.264	0.57	0.51	0.39
$\Delta \ln i$	-0.322	0.400	0.51	0.59	0.34
$\Delta \ln (c+i)$	0.106	0.264	0.56	0.52	0.40

Table B3: Gabon ($\alpha = 2.18$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	-0.005	0.106	1	0.15
$\Delta \ln c$	-0.039	0.166	-0.05	-0.55
$\Delta \ln i$	-0.108	0.542	0.64	0.26
$\Delta \ln (c+i)$	-0.036	0.178	0.72	0.09
$\Delta \ln p$	0.014	0.220	0.15	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.004	0.201	1	-0.54	-0.25
$\Delta \ln c$	0.043	0.217	0.23	0.68	-0.54
$\Delta \ln i$	-1.259	0.359	0.63	0.21	0.09
$\Delta \ln (c+i)$	0.041	0.195	0.31	0.62	0.03

Table B4: Gambia ($\alpha = 6.02$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	-0.008	0.093	1	0.15
$\Delta \ln c$	-0.046	0.190	0.93	0.21
$\Delta \ln i$	0.051	0.245	0.52	-0.12
$\Delta \ln (c+i)$	-0.036	0.181	0.95	0.20
$\Delta \ln p$	-0.046	0.180	0.15	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.204	0.085	1	-0.61	0.02
$\Delta \ln c$	0.173	0.118	0.17	0.67	0.23
$\Delta \ln i$	0.071	0.114	0.03	0.68	0.09
$\Delta \ln (c+i)$	0.176	0.113	0.15	0.68	0.23

Table B5: Mauritania ($\alpha = 5.36$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	-0.012	0.067	1	0.18
$\Delta \ln c$	-0.002	0.088	0.67	0.30
$\Delta \ln i$	-0.047	0.465	-0.02	0.25
$\Delta \ln (c+i)$	0.000	0.090	0.58	0.51
$\Delta \ln p$	-0.034	0.118	0.17	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.171	0.084	1	-0.72	-0.05
$\Delta \ln c$	0.148	0.078	0.32	0.41	0.05
$\Delta \ln i$	-0.019	0.071	0.38	0.22	0.17
$\Delta \ln (c+i)$	0.150	0.073	0.34	0.40	0.23

Table B6: Mauritius ($\alpha = 28.01$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.040	0.067	1	0.40
$\Delta \ln c$	0.039	0.091	0.94	0.51
$\Delta \ln i$	0.030	0.228	0.56	0.10
$\Delta \ln (c+i)$	0.040	0.087	0.98	0.46
$\Delta \ln p$	0.002	0.150	0.40	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.184	0.130	1	-0.35	0.17
$\Delta \ln c$	0.195	0.143	0.70	0.42	0.48
$\Delta \ln i$	0.279	0.116	0.78	0.27	0.05
$\Delta \ln (c+i)$	0.193	0.140	0.71	0.40	0.45

Table B7: Seychelles ($\alpha = 6.63$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.035	0.061	1	-0.02
$\Delta \ln c$	0.027	0.128	0.58	0.37
$\Delta \ln i$	0.011	0.255	0.45	-0.18
$\Delta \ln (c+i)$	0.031	0.088	0.82	0.18
$\Delta \ln p$	0.001	0.238	-0.02	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.139	0.113	1	-0.68	-0.11
$\Delta \ln c$	0.159	0.139	-0.16	0.82	0.14
$\Delta \ln i$	-0.015	0.144	-0.01	0.60	-0.07
$\Delta \ln (c+i)$	0.157	0.131	-0.15	0.82	-0.05

Table B8: Barbados ($\alpha = 12.86$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.024	0.037	1	0.01
$\Delta \ln c$	0.022	0.076	0.63	0.19
$\Delta \ln i$	0.008	0.165	-0.16	0.13
$\Delta \ln (c+i)$	0.023	0.058	0.64	0.24
$\Delta \ln p$	0.006	0.147	0.01	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.222	0.096	1	-0.53	-0.34
$\Delta \ln c$	0.235	0.108	0.35	0.60	0.08
$\Delta \ln i$	0.263	0.090	0.39	0.42	0.05
$\Delta \ln (c+i)$	0.234	0.105	0.36	0.59	0.15

Table B9: Jamaica ($\alpha = 0.59$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	-0.009	0.053	1	-0.37
$\Delta \ln c$	-0.007	0.110	0.77	0.77
$\Delta \ln i$	-0.056	0.231	0.26	0.26
$\Delta \ln (c+i)$	-0.012	0.072	0.94	0.94
$\Delta \ln p$	-0.019	0.082	-0.37	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.122	0.151	1	-0.25	-0.06
$\Delta \ln c$	0.109	0.152	0.88	0.84	-0.37
$\Delta \ln i$	0.285	0.123	0.84	0.84	-0.37
$\Delta \ln (c+i)$	0.107	0.152	0.88	0.88	-0.38

Table B10: Guyana ($\alpha = 186.14$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	-0.024	0.117	1	0.33
$\Delta \ln c$	-0.020	0.158	0.62	0.22
$\Delta \ln i$	-0.074	0.309	0.32	0.13
$\Delta \ln (c+i)$	-0.022	0.129	0.79	0.30
$\Delta \ln p$	-0.033	0.143	0.33	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.027	0.149	1	-0.35	0.24
$\Delta \ln c$	-0.002	0.175	0.56	0.56	0.33
$\Delta \ln i$	-0.563	0.236	0.65	0.39	0.03
$\Delta \ln (c+i)$	0.003	0.166	0.59	0.54	0.41

Table B11: Hong Kong ($\alpha = 14.41$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.055	0.043	1	0.08
$\Delta \ln c$	0.055	0.045	0.85	-0.21
$\Delta \ln i$	0.048	0.083	0.81	0.13
$\Delta \ln (c+i)$	0.053	0.048	0.95	-0.09
$\Delta \ln p$	-0.009	0.075	0.08	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.092	0.051	1	-0.27	-0.38
$\Delta \ln c$	0.082	0.087	0.45	0.72	-0.50
$\Delta \ln i$	0.159	0.047	0.46	0.49	-0.03
$\Delta \ln (c+i)$	0.084	0.075	0.47	0.72	-0.37

Table B12: Jordan ($\alpha = 6.85$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.023	0.085	1	-0.37
$\Delta \ln c$	0.025	0.108	0.87	-0.36
$\Delta \ln i$	-0.008	0.203	0.80	0.01
$\Delta \ln (c+i)$	0.021	0.116	0.94	-0.28
$\Delta \ln p$	-0.016	0.106	-0.37	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.040	0.082	1	-0.63	0.43
$\Delta \ln c$	0.029	0.087	0.26	0.57	-0.01
$\Delta \ln i$	0.054	0.076	0.24	0.52	0.34
$\Delta \ln (c+i)$	0.030	0.083	0.26	0.58	0.09

Table B13: Malaysia ($\alpha = 677.79$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.040	0.057	1	0.60
$\Delta \ln c$	0.032	0.070	0.89	0.57
$\Delta \ln i$	0.050	0.153	0.95	0.59
$\Delta \ln (c+i)$	0.039	0.091	0.99	0.61
$\Delta \ln p$	-0.016	0.112	0.60	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.068	0.080	1	-0.72	-0.30
$\Delta \ln c$	0.054	0.076	0.02	0.64	0.52
$\Delta \ln i$	-0.084	0.093	0.13	0.47	0.20
$\Delta \ln (c+i)$	0.059	0.070	0.07	0.63	0.55

Table B14: Singapore ($\alpha = 38.46$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.058	0.038	1	0.16
$\Delta \ln c$	0.044	0.027	0.73	0.18
$\Delta \ln i$	0.046	0.097	0.42	0.47
$\Delta \ln (c+i)$	0.046	0.045	0.65	0.44
$\Delta \ln p$	0.016	0.055	0.16	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.092	0.037	1	0.46	-0.03
$\Delta \ln c$	0.116	0.106	0.85	0.84	0.18
$\Delta \ln i$	0.068	0.038	0.21	0.77	0.27
$\Delta \ln (c+i)$	0.106	0.070	0.79	0.91	0.36

Table B15: Belgium ($\alpha = 1.39$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.023	0.027	1	0.02
$\Delta \ln c$	0.024	0.022	0.79	0.19
$\Delta \ln i$	0.017	0.102	0.91	0.03
$\Delta \ln (c+i)$	0.023	0.039	0.96	0.07
$\Delta \ln p$	-0.022	0.072	0.02	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.090	0.101	1	-0.40	0.37
$\Delta \ln c$	0.071	0.097	0.82	0.18	0.73
$\Delta \ln i$	0.126	0.090	0.84	0.15	0.13
$\Delta \ln (c+i)$	0.073	0.096	0.83	0.18	0.41

Table B16: Cyprus (α = 33.91)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.031	0.094	1	0.20
$\Delta \ln c$	0.033	0.080	0.95	0.23
$\Delta \ln i$	-0.006	0.236	0.96	0.02
$\Delta \ln (c+i)$	0.024	0.115	0.99	0.15
$\Delta \ln p$	-0.020	0.075	0.20	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.102	0.068	1	-0.69	0.03
$\Delta \ln c$	0.085	0.065	0.43	0.35	0.42
$\Delta \ln i$	0.068	0.051	0.55	0.05	-0.01
$\Delta \ln (c+i)$	0.087	0.057	0.48	0.30	0.24

Table B17: Ireland (α = 13.60)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.032	0.032	1	-0.04
$\Delta \ln c$	0.024	0.039	0.71	0.23
$\Delta \ln i$	0.017	0.132	0.65	-0.02
$\Delta \ln (c+i)$	0.024	0.051	0.89	0.10
$\Delta \ln p$	-0.028	0.105	-0.04	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.081	0.100	1	-0.50	0.23
$\Delta \ln c$	0.058	0.108	0.58	0.39	0.28
$\Delta \ln i$	-0.045	0.096	0.52	0.32	0.11
$\Delta \ln (c+i)$	0.061	0.097	0.60	0.39	0.41

Table B18: Malta ($\alpha = 5.69$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.054	0.029	1	0.16
$\Delta \ln c$	0.037	0.039	0.50	0.11
$\Delta \ln i$	0.039	0.115	0.55	0.28
$\Delta \ln (c+i)$	0.039	0.047	0.65	0.31
$\Delta \ln p$	0.004	0.076	0.16	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.065	0.053	1	-0.63	0.17
$\Delta \ln c$	0.071	0.060	0.14	0.67	0.04
$\Delta \ln i$	0.062	0.050	0.12	0.57	0.25
$\Delta \ln (c+i)$	0.071	0.055	0.14	0.68	0.28

Table B19: Netherlands ($\alpha = 0.81$)

Actual Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	0.016	0.018	1	0.09
$\Delta \ln c$	0.018	0.018	0.51	0.01
$\Delta \ln i$	-0.002	0.091	0.74	0.19
$\Delta \ln (c+i)$	0.013	0.027	0.89	0.20
$\Delta \ln p$	-0.015	0.111	0.09	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.123	0.113	1	-0.42	0.11
$\Delta \ln c$	0.116	0.110	0.79	0.22	0.38
$\Delta \ln i$	-0.001	0.124	0.78	0.23	-0.04
$\Delta \ln (c+i)$	0.115	0.110	0.79	0.22	0.06

Table B20: Papua New Guinea ($\alpha = 20.37$)

Actual Values

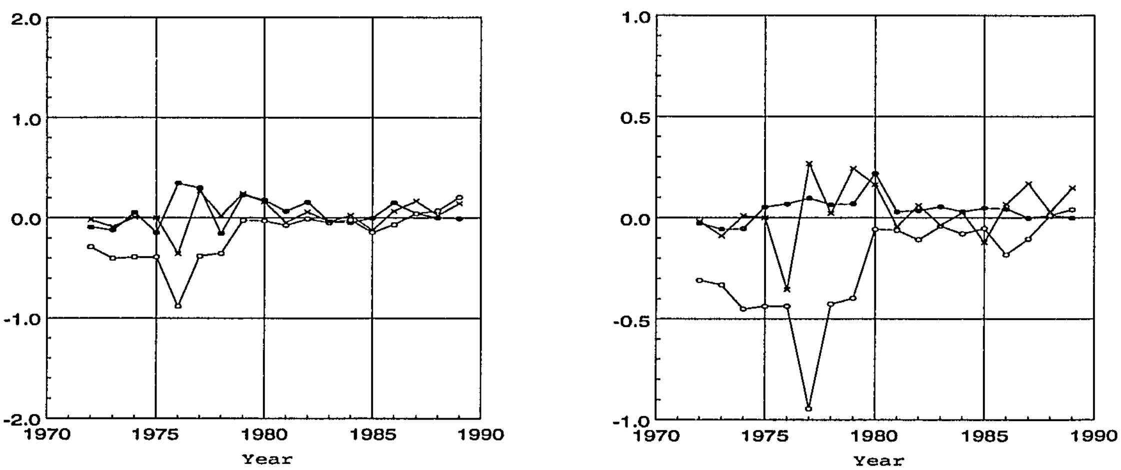
Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$
$\Delta \ln y$	-0.014	0.025	1	-0.15
$\Delta \ln c$	0.001	0.041	0.62	0.12
$\Delta \ln i$	-0.084	0.232	0.06	-0.19
$\Delta \ln (c+i)$	-0.019	0.051	0.43	-0.18
$\Delta \ln p$	-0.030	0.139	-0.15	1

Simulated Values

Variable	Mean	Standard Deviation	Correlation with $\Delta \ln y$	Correlation with $\Delta \ln p$	Correlation with Actual
$\Delta \ln y$	0.090	0.091	1	-0.51	0.55
$\Delta \ln c$	0.065	0.121	0.28	0.28	0.37
$\Delta \ln i$	0.114	0.106	0.30	0.30	-0.03
$\Delta \ln (c+i)$	0.068	0.116	0.29	0.29	0.20

APPENDIX C

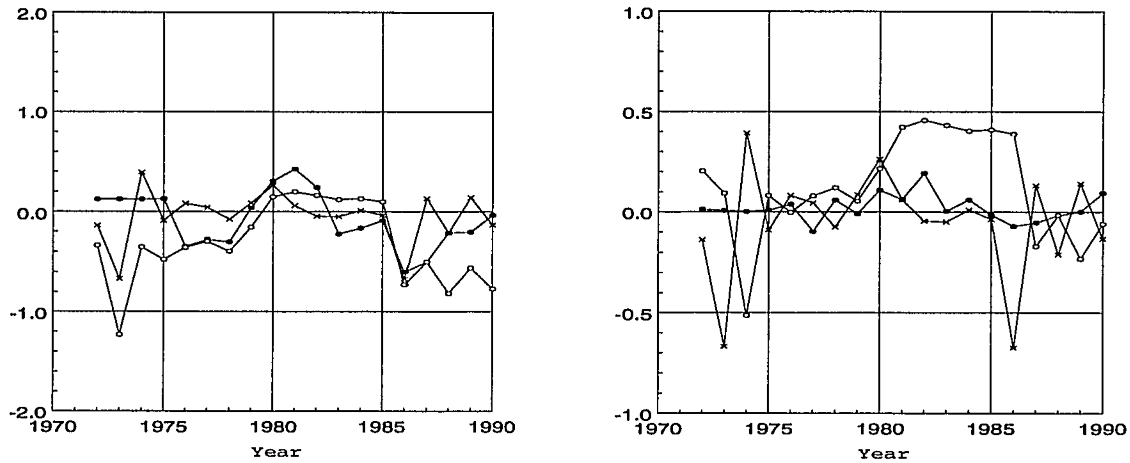
Actual and Simulated Investment and Output Growth Rates



(a) Investment (b) Output

●: actually observed growth rates
O: simulated growth rates
×: terms-of-trade growth rates

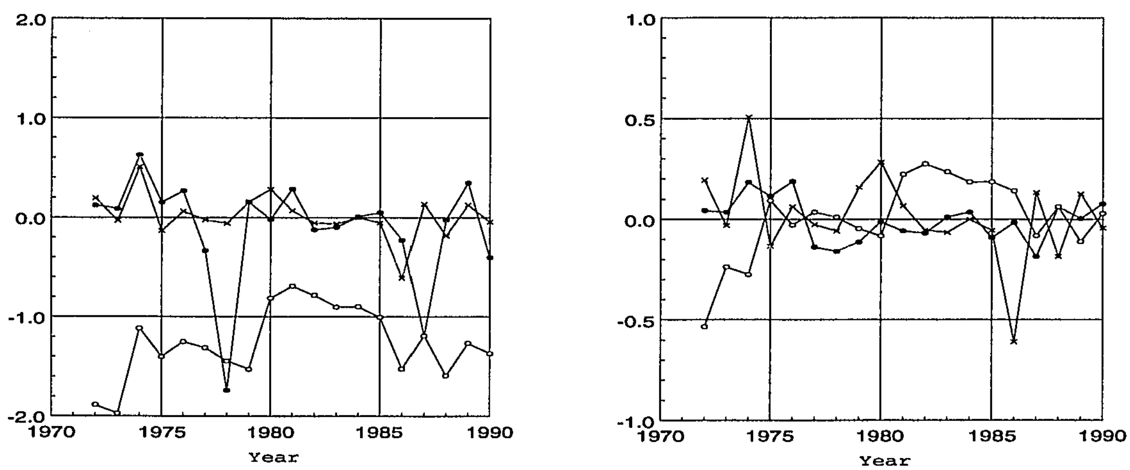
Figure C1: Cape Verde



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

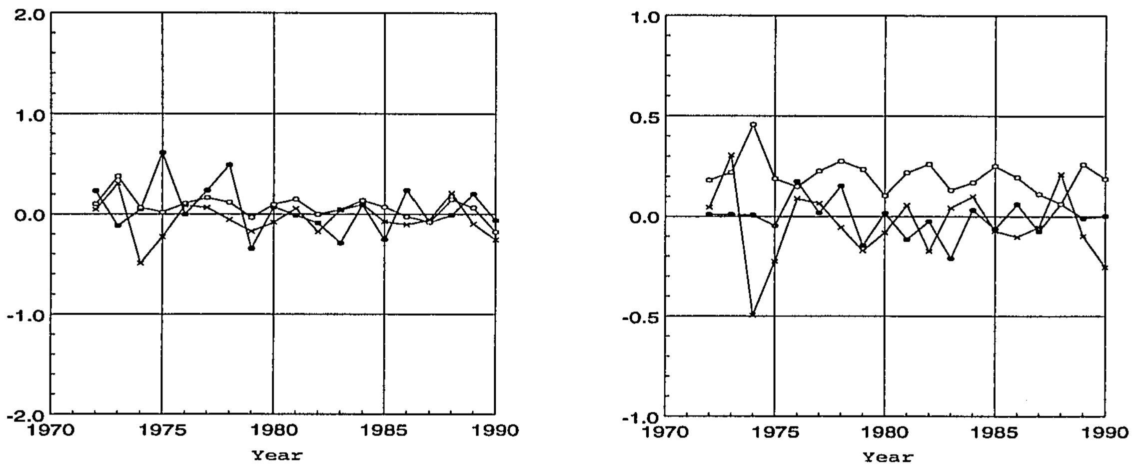
Figure C2: Congo



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

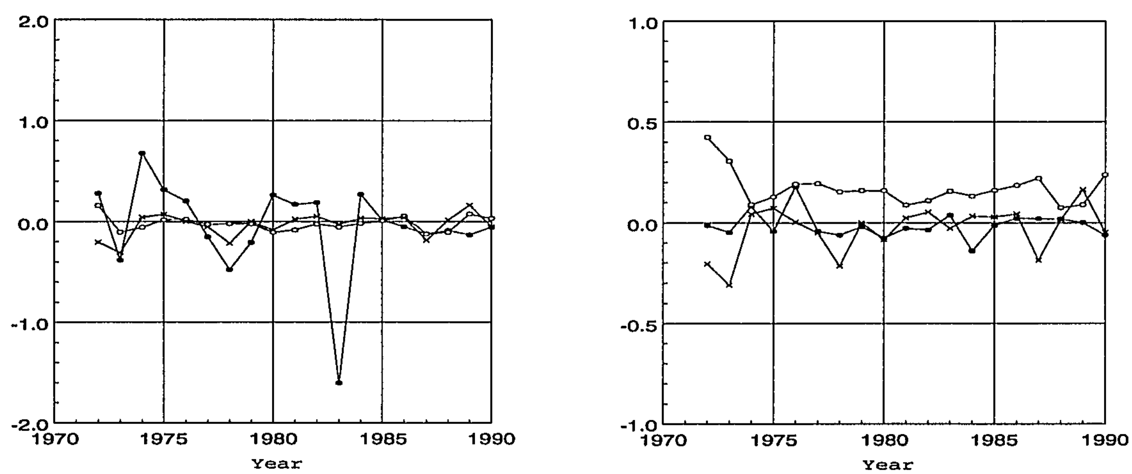
Figure C3: Gabon



(a) Investment (b) Output

●: actually observed growth rates
O: simulated growth rates
×: terms-of-trade growth rates

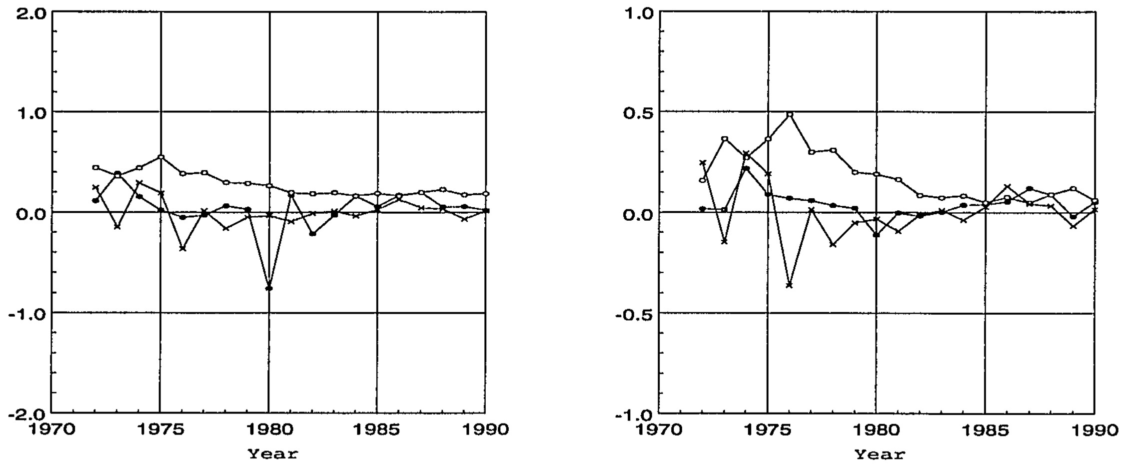
Figure C4: Gambia



(a) Investment (b) Output

●: actually observed growth rates
O: simulated growth rates
×: terms-of-trade growth rates

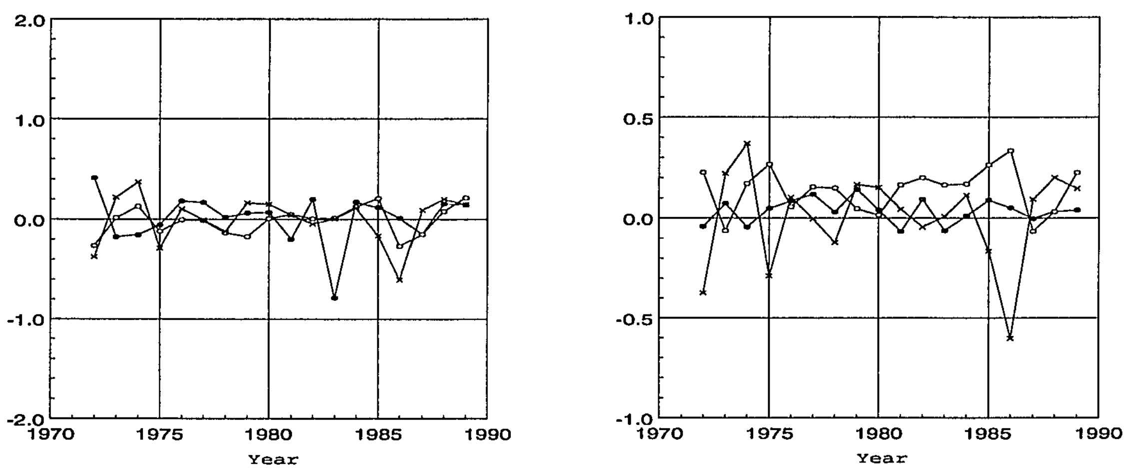
Figure C5: Mauritania



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

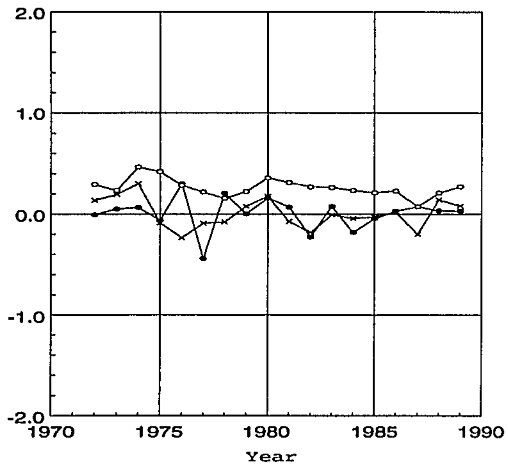
Figure C6: Mauritius



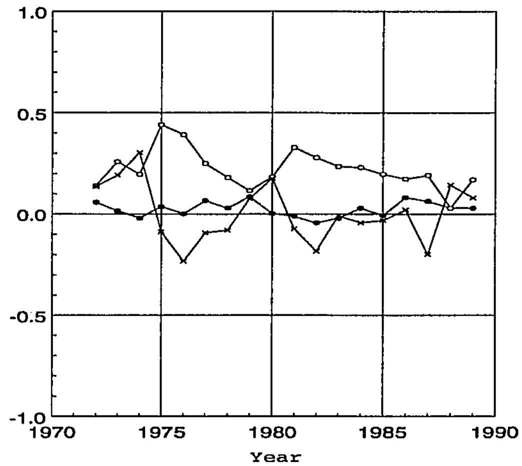
(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C7: Seychelles



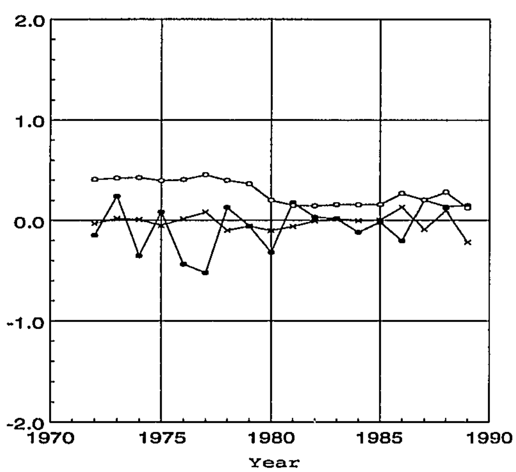
(a) Investment



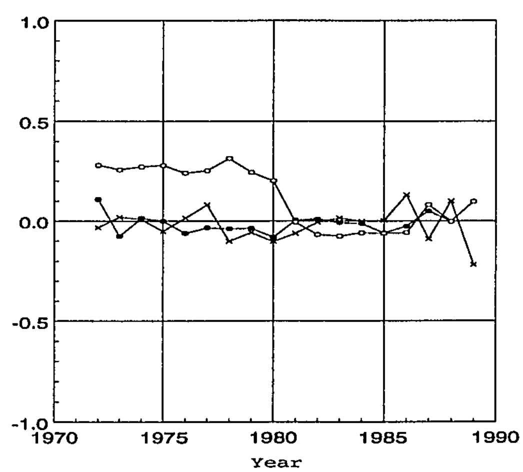
(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C8: Barbados



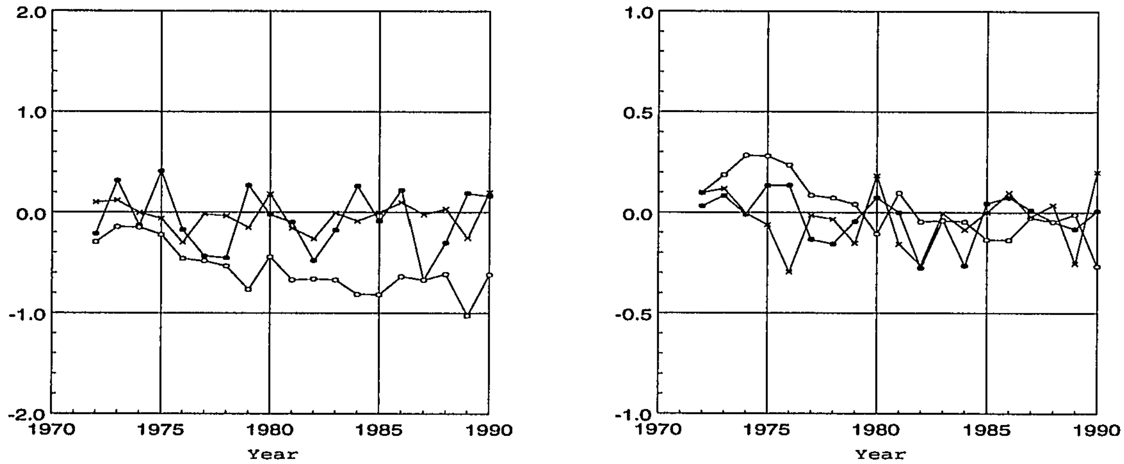
(a) Investment



(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

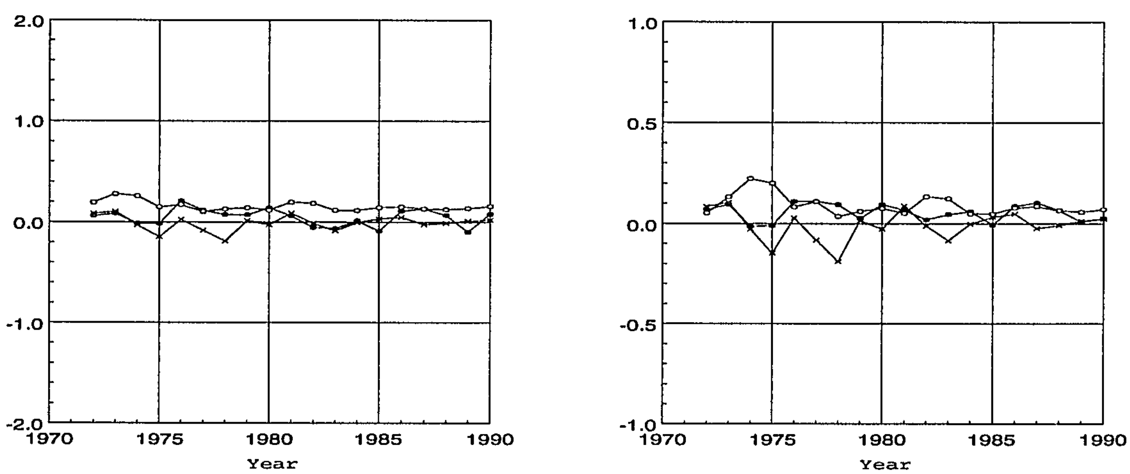
Figure C9: Jamaica



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

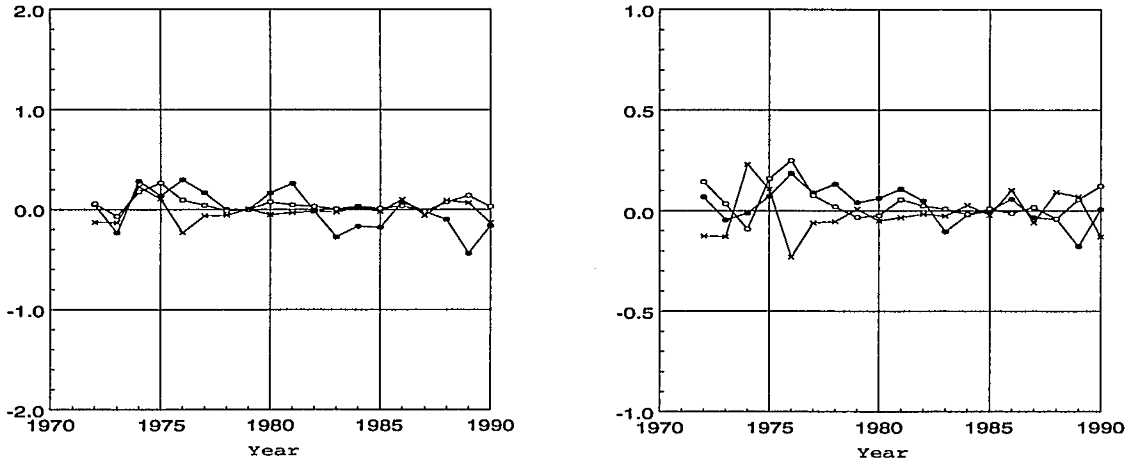
Figure C10: Guyana



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

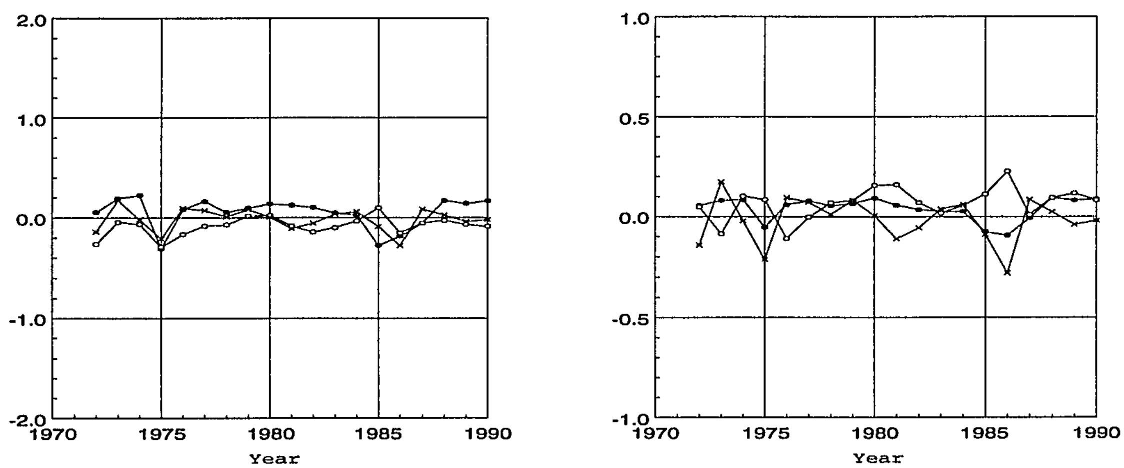
Figure C11: Hong Kong



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

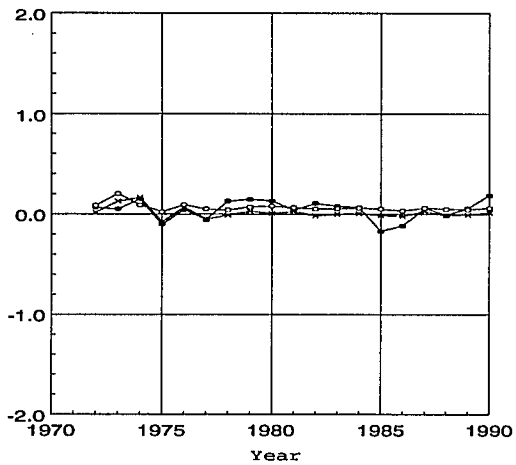
Figure C12: Jordan



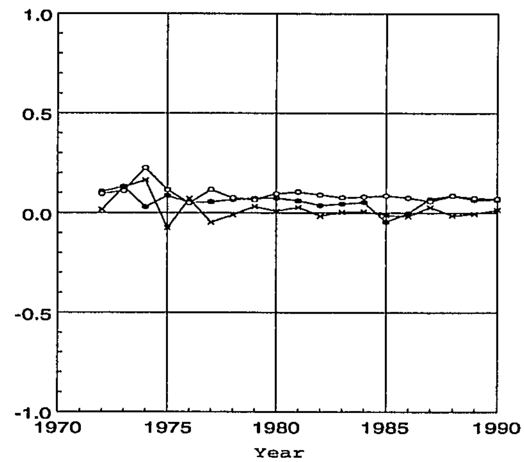
(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C13: Malaysia



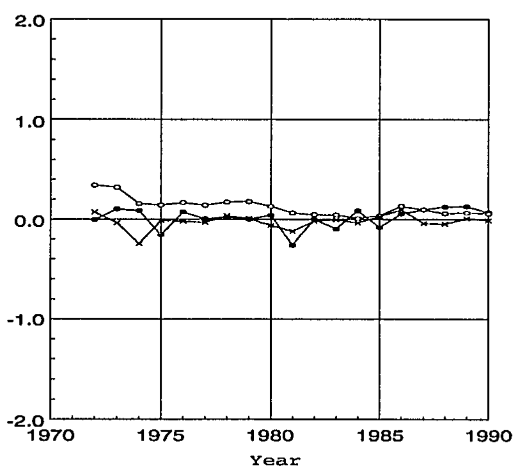
(a) Investment



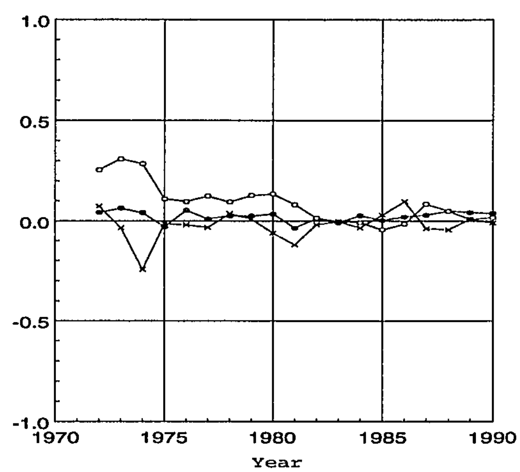
(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C14: Singapore



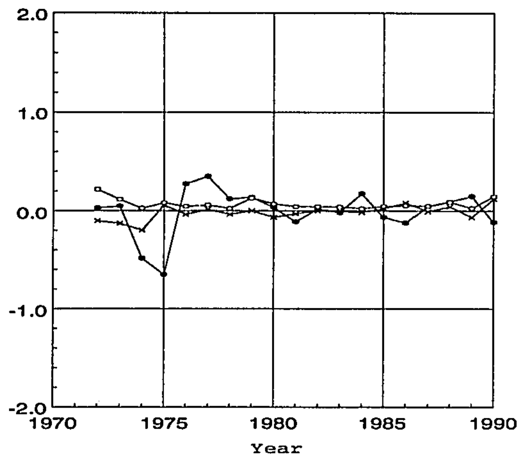
(a) Investment



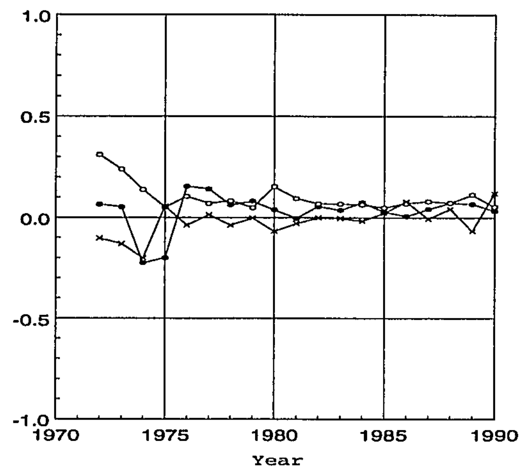
(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C15: Belgium



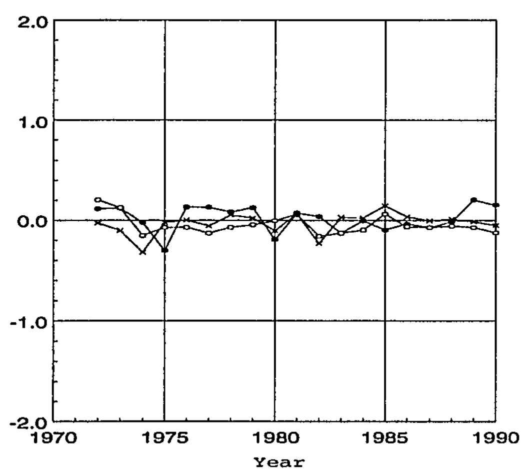
(a) Investment



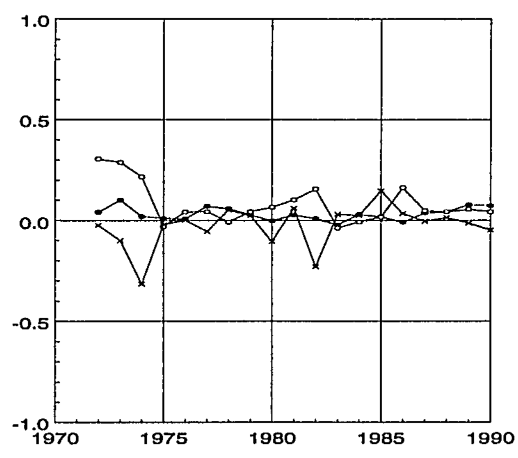
(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C16: Cyprus



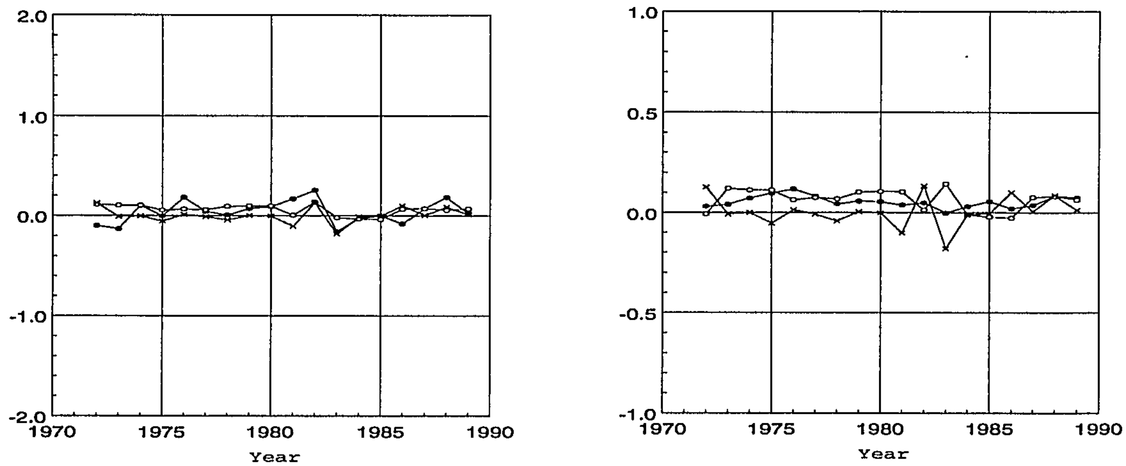
(a) Investment



(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C17: Ireland

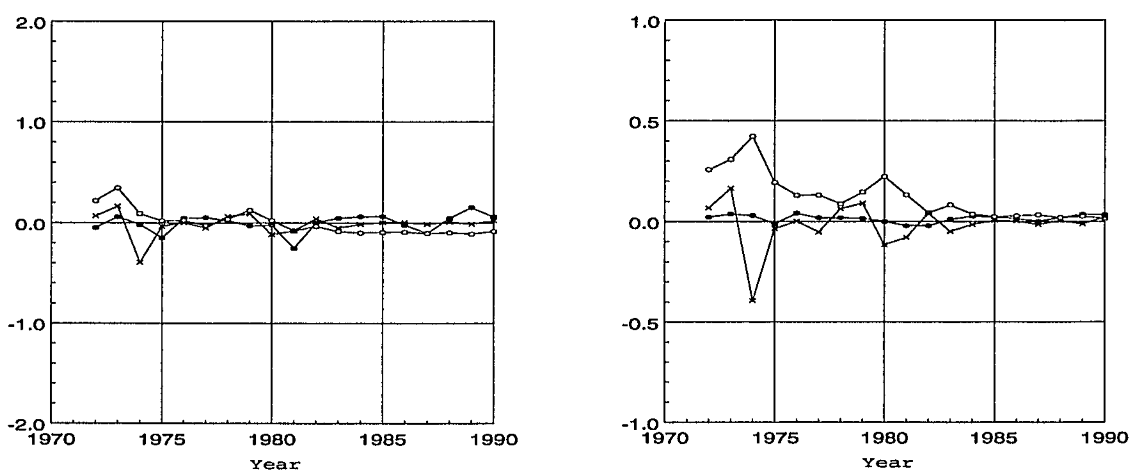


(a) Investment

(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C18: Malta

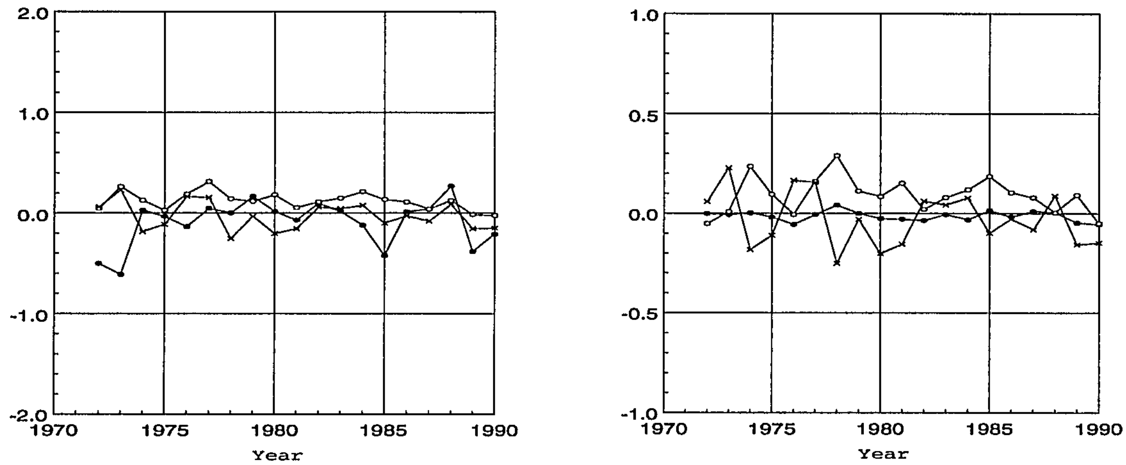


(a) Investment

(b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C19: The Netherlands



(a) Investment (b) Output

●: actually observed growth rates
○: simulated growth rates
×: terms-of-trade growth rates

Figure C20: Papua New Guinea

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