Culture as a Source of Comparative Advantage

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26 November 2004

Abstract

We show that small open economies with identical endowment, technology, and preferences can have different trade patterns, depending on how a public productive input (e.g. the quality of the environment) is supplied by individuals in the economy. In some economies, individuals may adopt static Nash behaviour, and this results in a (static) Nash equilibrium supply of the public good. In other economies, each individual expects that other individuals in the economy use a behavior rule that conditions their public good contribution on the level of trust in the society, and consequently he has an incentive to build up the social level of trust. This can result in a higher level of public good and superior performance in terms of welfare at any given world relative price. These economies will have comparative advantage in the production of the environment-sensitive good. If the rate of discount is small enough, the steady state of economies with non-static Nash-behaviour can approximate what a social planner for would want to achieve.

Date: 22 November 2004, filename:culturaldeterminant2004nov26.tex

Keywords: Culture, Comparative Advantage, Environmental Quality

JEL Classifications:D80, D83

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Acknowledgements: The authors wish to thank Alan Deardorff, Ronald Findlay, Kim Long, Henry Wan Jr., and Ping Wang discussions. Financial supports from SSHRC and FQRSC are gratefully acknowledged.

1. Introduction

The purpose of this paper is to present a formal model to illustrate the idea that differences in culture can be a major determinant of the pattern of trade among countries.

The traditional explanations of trade point to three sources: (i) difference in technology, as exemplified by the Ricardian trade model, (ii) differences in relative endowments of factor of production, as captured by the Heckscher-Ohlin model, and (iii) differences in preferences, as reflected by differences in the per-period indifference maps of the representative consumers (see Harry Johnson[1], 1959, and Mitra and Trindale, 2004, for example), or by differences in the rate of time preference, as in the model of trade involving durable goods by Shimomura (1995).

It seems the consensus is that under the assumptions that markets are perfectly competitive, countries trade with each other only if they are different from each other in at least one of the three categories mentioned above. (Of course, once we depart from perfect competition and introduce fixed costs and monopolistic competition, countries can trade with each other even though they are ex ante identical; they choose to specialize in different products, as pointed out by Krugman and Helpman).

This paper draws attention to another source of difference that accounts for trade: cultural differences. We wish to make a clear distinction between cultural differences and differences in tastes (of the type included in (iii) above). Two countries can have identical tastes (i.e., identical per-period indifference maps and identical rate of time preference) but different cultures. For example, in one country, individuals rationally adopt static Nash behaviour, while in another country individuals (also rationally) adopt dynamic Nash behaviour

[1] In Johnson (1959) and Mitra and Trindale (2004), individuals may have the same non-homothetic indifference maps, but the "representative individuals" of different countries can have different demand patterns, because of different degrees of income inequality within each country.

that is conditional on their social history. We will show that in such cases, there exist incentives to trade.

We will present a very specific model that explains trade in terms of cultural differences. We have no intention to discuss all relevant aspects of the trade-culture nexus, nor even to present a definition of culture. Perhaps the following anecdote will explain our chosen narrow focus.

One day, an old man was walking along a beach, pondering over a deep problem. He saw a little boy in the process of digging a little hole in the sand, using a plastic spade and holding a plastic bucket. "What are you doing, little one?" asked the old man. "Sir, I am digging a hole, and with this bucket I am going to pour into this hole all the water from the ocean." The old man could not contain his laugh, and said: "Little one, you should go home now. How futile is your effort!" But suddenly he realized that his effort was no different from the boy's: he was trying to write an article about culture, using the limited knowledge and tools of an economist.

Briefly, our basic model is as follows. We modify the Heckscher-Ohlin model by adding a public input which is a local public good, say the quality of the environment. There are two consumption goods, say apple and banana. We suppose that the apple-producing technology is more sensitive to the quality of the environment, in the sense that, at any constant relative price, an increase in the quality of the (local) environment will increase the output of apples relative to the output of bananas. Individuals in an economy contribute efforts which have a positive effect on the quality of the local environment.Thus they engage in a game of voluntary private contribution to a public input. We argue that this game can have many equilibrium outcomes, depending on the behaviour patterns of the individuals, which basically reflect different national cultures. In some socities, individuals behave as if their social history of contributions to public good did not matter. Then they rationally choose to contribute the static Nash equilibrium levels of efforts. In other societies, each may adopt behaviour which takes into account the history of trust and reciprocity. Their mode of behaviour may be called called "Better-than-static-Nash Behaviour" or "Optimistic Behaviour" for short. They achieve an equilibrium which results in a higher level of environmental quality. Naturally, economies where individuals adopt "Optimistic Behaviour" will have comparative advantage in the production of the environment-sensitive consumer good.

Our model is about the effects of cultural differences on comparative advantage. This is to be distinguished from popular debates about the effects of culture on absolute advantage. As an example of this, let me quote Lee Kwan Yew's "From Third World to First" (2000):

"Indeed, the Japanese has admirable qualities. Theirs is a unique culture...One-to-one, many Chinese can match the Japanese, whether it is at Chinese chess or the game of Go. But in a group, especially a production team in a factory, they are difficult to beat...The Japanese worker would cover for his work-mate who had to attend to other urgent business; the Singapore worker looked only after his own job."(p. 580)

Lee Kwan Yew did touch on the topic of voluntary contributions to a public good in societies with different cultures (Kobe versus Los Angeles):

"The behaviour of the people of Kobe after a massive earthquake in 1995 was exemplary and impressive. Riots and looting followed in Los Angeles in 1992 after a less devastating earthquake whereas the Japanese in Kobe reacted stoically. There was no looting or rioting. Japanese companies mounted their own rescue efforts...; voluntary organisations came forward to help without any prompting."(p. 588)

The paper is organized as follows. In Section 2, we reviewed some recent papers that deal with the trade-and-culture nexus. In Section 3, we present a modified Heckscher-Ohlin model with an additional input that is provided by voluntary contribution. In Section 4, we determine the equilibrium under static-Nash behaviour, and points out that countries with "Optimistic Behaviour" will have a comparative advantage in the production of the environment-sensitive consumption good. Sections 5 and 6 offer two alternative explanations of how the "Optimistic Behaviour" may come about. Section 7 discusses some welfare implications. We offer some concluding remarks in Section 8.

2. A Review of Recent Models on Trade and Culture

Before presenting our model, we briefly review a few recent papers that deal with the cultural dimension of trade.

Concerns have been expressed in many circles on possible detrimental effects of globalization on cultural diversity. In some countries, policy makers have taken these concerns very seriously. Canada and France are two G7 countries that have in place policies to prevent the possible loss of cultural identity that might result from free trade. France has restrictions on foreign films and television programs from English-speaking countries, while Canada requires minimum level of Canadian content in radio and television broadcast. Canadian magazines are protected by government tax laws that discriminate against Canadian companies that place their advertisements in foreign magazines imported into Canada (in particular, US-based magazines such as Sports Illustrated, Time, etc.). Similarly, South Korea has restrictions on music CD's imported from Japan.

There are, however, very few formal models of effects of trade on culture, or on welfare (which includes cultural identity as an argument). Four recent papers deal with four different aspects of the trade-and-culture nexus. Janeba (2004) formalizes the notion of cultural identity and incorporates it in a Ricardian model of trade. He adopts the "indentity function" formulation of Akerlof and Kranton (2000), whereby (i) a person suffers a utility loss if some individuals in his country deviates from the social norms, and (ii) an individual who deviates from social norms incurs a direct utility loss for the self-inflicted loss of identity (but he may still achieve a net gain in doing so, when the foreign good becomes sufficiently cheap). One of Janeba's results is that trade is not always Pereto superior to autarky. This is because of the public good aspect implied by (i) above. Suranovic and

Winthorp (2003) present two models of trade in which consumers or workers care about culture. In their first model, called the "cultural affinity from work" model, workers in a particular industry receive non-pecuniary cultural benefits (NPCB) from work. If trade liberalization causes this industry to decline, the gains from trade in the case where NPCB exist are smaller than under the standard textbook case. In their second model, called the "cultural externality model," consumption of the home-produced culture good by each person in the home country has a positive external effect on all his compatriots. As a result, the optimal tariff is positive even if the country is a small open economy (even though the tariff is inferior to a consumption subsidy). Francois and Ypersele (2002) consider the protection of a cultural good the production of which involves a fixed cost. A tariff on Hollywood movies can be Pareto superior to free trade if it makes local movies viable.

Bala and Long (2004) focus on a different aspect of the problem of trade and culture: the effects of trade on the *evolution* of preferences.They provide a dynamic model which shows that, in the long run, free trade may result in the demise of cultural diversity: a relatively small country may gradually lose its cultural identity when it engages in free trade with a larger country that has a different preference pattern. Relative world price is endogenous in this model, and changes over time as the distribution of preferences evolves in each economy.

The approach used by Bala and Long (2004) is based on the biological evolutionary theory, but the model must be interpreted in a broader sense, as it will become clear in what follows. The argument that preferences evolve is basically drawn from the Darwinian theory of evolution[2]. Another important cause for preference changes is *imitation*, which can happen if, for instance, people have preferences for conformity (such as keeping up with the Joneses, etc., see Stephen

[2]Evolution-based explanation of of the prevalence of certain preference traits in human societies has been provided by Cavalli-Sforza and Feldman (1973), Hirschleifer (1977,1978), Bergstrom (1995), Robson (1996), and others.

R. Jones, 1984), or if there are network externalities of the social or informational type (see, e.g., Schelling, 1978, Rogers, 1983, Katz and Shapiro, 1986, Arthur, 1989, Karni and Schmeider, 1990, Bhikchandani, Hirschleifer, and Welch, 1992). Imitation may be favored by many factors, such as conformity pressure, or relative cheapness. If a good is abundant, its price is likely to be low, and the number of users of the good will be high. This in turn increases the possibility of imitation and thereby raises the representation of preferences favoring this good in the population.[3]

Another possibility for natural selection is due to *learning-by-doing.* Finally, *habit formation* may also induce preference selection. Children growing up in environments where certain habits (such as music appreciation or taste for spicy foods) are prevalent among adults are likely to acquire them as well. Thus these preferences are transmitted across generations (Becker, 1993). The more easily available is the good, the greater the capacity for it to become part of a habit, and the higher is the possibility that such preferences will be selected over time.

The model of Bala and Long (2004) is formulated in discrete time. In each period, adults make their consumption decisions, and leave no bequests. This period's chidren are next period's adults. The fitter adults have relatively more "children". "Children" inherit the preference traits of their "parents". Here the words "children" and "parents" must be interpreted in the "cultural sense" rather than the biological sense. Biologically sterile individuals can have "children" in the sense that they can have cultural influence on members of the next generation. Thus, a "gene" may be interpreted in the sense of a cultural gene, that is, a "meme" (a word coined by Dawkins, 1986, to mimic

[3] Conformity or herd behavior may in some cases be a more important factor. A preference shock in favor of a commodity raises the demand for it, and also raises its price. The former effect may cause a second round of increased demand: more people will consume the good due to conformity pressure. The price rise may be able to provide a powerful countervailing force. For a model of trade and culture that emphasizes conformity, see Janeba (2004).

the biological concept of gene.) Bala and Long (2004) do not however model the conscious decision of adults to spend resources to spread their "memes". For models along these lines, see Bisin and Verdier (2000, 2001) in which "preferences of children are acquired through an adaptation and imitation process which depends on their parents' socialization actions, and on the cultural and social environment in which children live."(Bisin and Verdier, 2001, p.299.)

Bala and Long (2004) show that if the relative supply of the two goods is not too extreme, then there exists a *heterogenous* distribution[4] of preferences in the population, which is globally stable. The stability is ensured by the price mechanism interacting with the dynamics of changes in the preference distribution. On the other hand, if the bundle is at one extreme, then one type of preference will be wiped out in the long-run.

After characterizing autarkic equilibrium, Bala and Long (2004) turn to an analysis of trade between two economies with different preference patterns at the time trade opens, and the resulting changes in preferences within each economy. They show that if one economy is much larger than the other, then in the long run the distribution of preferences in the small economy under free trade will be identical to the autarkic long-run pattern of preferences of the large economy, in other words, the small economy will lose its cultural identity. In particular, it is possible that under autarky the small economy has a stable *heterogenous* distribution of preferences, and under free trade, both countries end up with only one (and the same) preference type.

The idea of natural selection of preferences is not new. Becker (1976) discusses the evolution of altruism using the concept of genetic fitness; Hansson and Stewart (1990) mention intergenerational savings in the context of preference selection; Rogers (1994) models the evolution of the rate of time preference by natural selection. Bisin

[4]Bisin and Verdier (2001, p.300) also obtained a stable long-run heterogenous distribution, but they relied on the assumption of substitutability between (a) parents' efforts of socializing their children, and (b) children's cultural adaptation and imitation from society at large.

and Verdier (2000,2001) focus on parents' time-allocation decision to socialize their children. In contrast to these papers, Bala and Long study the link between *relative scarcity of different goods* and preference evolution.

More generally, Bala and Long's work is related to the literature dealing with the alteration of tastes over time due to social influences or habit formation (see, e.g., Leibenstein, 1950, von Weizsacker, 1971, Pollack, 1976, Becker and Murphy, 1989, Leonard, 1989, Karni and Schmeidler, 1990, and Pesendorfer, 1995).

3. A Model of Comparative Advantage based on Cultural Differences

We consider a world with a large number of countries that have identical relative endowments, identical technology, and identical population size.In each country, there is a local public good which affects productivity of privately owned factors of production. Each country has n individuals, and all individuals in this world have the same per period utility function and the same rate of time preference. All individuals are selfish: each cares only about his utility which depends only on his private consumption. Countries however differ in culture. Here we focus on only one aspect of culture, namely the pattern of social interaction in the private provision of public good.

We distinguish two modes of social interaction. The first mode is called Static-Nash Behaviour. The second mode is called Forward-Looking Behaviour, which can be of the optimistic or pessimistic type. (We will focus mainly on the optimistic type, since the analysis of the pessimistic type is similar, as can be seen in the appendix). We will show that the two modes of behaviour give rise to differences in comparative advantages. We will also show that the second mode of social interaction is consistent with our postulate that individuals are selfish. This is done in two different sections, Sections 5 and 6. In Section 5, we retain the static framework, and use the well-known concept of conjectural variation. In Section 6 we consider an infinite horizon model, and rely on the concept of Markov-Nash equilibrium strategies.

3.1. Basic Assumptions

Each country consists of n identical individuals. Each individual owns T units of land, and K units of capital. We set $K = T = 1$ for simplicity. There are two consumption goods, apple and banana. They are produced using land and capital, under neoclassical constant returns to scale technology. Labour is not an input in the production of apple and banana. Each individual uses his land and capital to produce the two outputs. Assume one good is more capital intensive than the other. This implies that each individual has a strictly concave transformation curve.

There is a third, non-priced factor of production, which we call "the quality of the environment," denoted by G. This factor is a local (i.e. country-specific) public good. G is produced by voluntary contributions of efforts g_i:

$$G = \sum_{i=1}^{n} g_i$$

A possible interpretation is that G represents the quality of the waterways. If each individual takes care by not dumping garbage into the waterways, G will be high. The quantity g_i represents the amount of care exercised by individual i.

We assume that for any given endowment of land and capital, a higher G will enable each individual to produce more (or no less) of both consumption goods. In addition, we assume that at any given relative price of apple in terms of banana, an increase in G will lead to an increase in the profit-maximizing level of apple output, and a decrease in the profit-maximizing level of banana output. In other words, any increase in G will be biased in favour of apple production (at constant relative price).

Example 1: Let Q_B and Q_A denote the outputs of banana and apple in the farm owned by the representative individual. We may assume that the transformation curve (or production possibilities frontier, PPF) of the farm is represented by the function

$$Q_B = \phi(Q_A, G) = E - \left(\frac{1}{G}\right)^{1/\varepsilon} \left(\frac{1}{\varepsilon} + 1\right)^{-1} (Q_A)^{\frac{1}{\varepsilon}+1}$$

where $\varepsilon > 0$ and $E > 0$ and where

$$0 \leq Q_A \leq Q_{A\max}$$

with

$$Q_{A\max} = \left[\frac{(1+\varepsilon)EG^{1/\varepsilon}}{\varepsilon}\right]^{\varepsilon/(1+\varepsilon)}$$

Let p denote the price of apple in terms of banana

$$p \equiv \frac{P_A}{P_B}$$

Given G, each farmer maximizes the value of outputs subject to the PPF.

$$\max pQ_A + \phi(Q_A, G)$$

This yields the first order condition for an interior maximum:

$$p = \phi_{Q_A} = \left(\frac{Q_A}{G}\right)^{1/\varepsilon}$$

Hence the supply functions are

$$Q_A^* = Gp^{\varepsilon} \tag{1}$$

for

$$0 \leq p^{\varepsilon} \leq \frac{Q_{A\max}}{G}$$

and

$$Q_B^* = E - \left(\frac{\varepsilon}{1+\varepsilon}\right) Gp^{1+\varepsilon} \tag{2}$$

The revenue function is then

$$R(P_A, P_B, G) = P_A Q_A^* + P_B \phi(Q_A^*, G) = P_B E + \left(\frac{1}{1+\varepsilon}\right) P_B G \left(\frac{P_A}{P_B}\right)^{1+\varepsilon} \tag{3}$$

It is easily verified that R is homogeneous of degree 1 in (P_A, P_B). We have in this example

$$R_G > 0$$

$$R_{GG} = 0$$

More generally, we use a general revenue function

$$Y = R(P_A, P_B, G)$$

with the following properties

$$\frac{\partial R}{\partial P_A} = Q_A^*$$

$$\frac{\partial R}{\partial P_B} = Q_B^*$$

$$\frac{\partial^2 R}{\partial G \partial P_A} = \frac{\partial Q_A^*}{\partial G} > 0 \tag{4}$$

$$\frac{\partial^2 R}{\partial G \partial P_B} = \frac{\partial Q_B^*}{\partial G} < 0 \tag{5}$$

Furthermore, R is homogeneous of degree 1 in (P_A, P_B).

We also assume that

$$R_G > 0$$

$$R_{GG} \leq 0.$$

Since G refers to the quality of the environment, from the assumptions (4) and (5), we may say that apple is the "**environment-sensitive good.**"

Turning now to preferences, we assume that each individual has a linear homogeneous utility function $U(C_A, C_B)$ with the usual neo-classical properties. This gives rise to an indirect utility function of the form

$$V(P_A, P_B, Y) = \frac{Y}{c(P_A, P_B)}$$

where$Y$ is nominal income, and $c(P_A, P_B)$ is the minimum amount of income needed to achieve one unit of utility.It is well knwn that $c(P_A, P_B)$ is increasing, concave, and homogeneous of degree 1 in (P_A, P_B).

Remark: Take the example

$$U = C_A^{\alpha} C_B^{1-\alpha} \tag{6}$$

then

$$c(P_A, P_B) = \Omega P_A^{\alpha} P_B^{1-\alpha} \text{ where } \Omega = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$$

It will be useful to compute autarkic equilibrium for a given G. Assuming (6), (1) and (2), we get

$$\frac{P_A C_A}{P_B C_B} = \frac{\alpha}{1-\alpha} = \frac{P_A Q_A}{P_B Q_B} = \frac{G p^{1+\varepsilon}}{E - \left(\frac{\varepsilon}{1+\varepsilon}\right) G p^{1+\varepsilon}}$$

The autarkic price is then, for a given G,

$$p^{AU} = \left\{ \frac{(1+\varepsilon)\alpha E}{\left[(1-\alpha)+\varepsilon\right] G} \right\}^{1/(1+\varepsilon)} \tag{7}$$

Thus the higher is the contribution to the public good, the lower is the autarkic price of the environment-sensitive good (in terms of good B). This is because, at any given price, the greater is G, the higher is the country's relative supply of good A.

However, G is not given. The next section will deal with this issue.

3.2. Voluntary contribution to the public input

Each individual in the country knows that

$$G = \sum_{i=1}^{n} g_i$$

Assume that g_i is measured in units of effort (it is the amount of efforts the individual uses to take care of the environment). In providing g_i, the individual incurs a cost, i.e., the disutility of efforts, represented by $D(g_i)$. We assume that $D(g_i)$ is convex and increasing, with

$$D'(0) = 0, \lim_{g \to \infty} D'(g) = \infty.$$

Let G_{-i} denote the total contribution of all other individuals in the country:

$$G = G_{-i} + g_i$$

Taking prices as given, the individual chooses g_i to maximize his net utility

$$u_i = \frac{Y}{c(P_A, P_B)} - D(g_i)$$

where Y is the income (value of outputs):

$$Y = R(P_A, P_B, G_{-i} + g_i)$$

Using linear homogeneity, we can define real income in terms of good B as:

$$y = \frac{Y}{P_B} = R\left(\frac{P_A}{P_B}, 1, G_{-i} + g_i\right) \equiv y(p, G_{-i} + g_i)$$

Then

$$\frac{Y}{c(P_A, P_B)} = \frac{y}{c\left(\frac{P_A}{P_B}, 1\right)} = \frac{y}{c(p, 1)}$$

Thus, the individual chooses g_i to maximize his net utility

$$u_i = \frac{y(p, G_{-i} + g_i)}{c(p,1)} - D(g_i) \tag{8}$$

Example 1(continued): Using (3) we get

$$y(p, G_{-i} + g_i) = E + \left(\frac{1}{1+\varepsilon}\right)(p)^{1+\varepsilon}(G_{-i} + g_i) \tag{9}$$

Assume

$$D(g_i) = \frac{1}{2} g_i^2 \tag{10}$$

Then

$$u_i = \left(\frac{1}{c(p,1)}\right)\left[E + \left(\frac{1}{1+\varepsilon}\right)(p)^{1+\varepsilon}(G_{-i} + g_i)\right] - \frac{1}{2} g_i^2 \tag{11}$$

and if the utility function $U(C_A, C_B)$ is Cobb-Douglas, then

$$c(p,1) = \Omega p^{\alpha} \tag{12}$$

4. Static-Nash Behaviour versus Optimistic Behaviour

Under the static Nash behaviour, each individual i takes G_{-i} as given. He chooses g_i to maximize the net utility u_i. The first order condition is

$$\frac{y_G(p, G_{-i} + g_i)}{c(p,1)} - D'(g_i) = 0$$

The second order condition is

$$\frac{y_{GG}(p, G_{-i} + g_i)}{c(p,1)} - D''(g_i) < 0$$

Let g^N denote the symmetric static Nash equilibrium contribution. It is implicitly defined by:

$$\frac{y_G(p, ng^N)}{c(p,1)} - D'(g^N) = 0 \tag{13}$$

Since the curve y_G is downward sloping, and the curve $D'(g)$ is upward sloping, the symmetric static Nash equilibrium is unique.

Example 1 (continued): Using (9) and (10), we obtain from (13) the symmetric Nash equilibrium contribution

$$g^N = \left(\frac{1}{c(p,1)}\right)\left(\frac{1}{1+\varepsilon}\right)(p)^{1+\varepsilon} = \left(\frac{1}{\Omega}\right)\left(\frac{1}{1+\varepsilon}\right)(p)^{1-\alpha+\varepsilon} \tag{14}$$

It follows that, for a small open economy, the higher is the world relative price of the environment-sensitive good, the greater is the resulting static Nash equilibrium contribution.

It is easy to see that the socially optimal level of contribution, denoted by g^{so}, exceeds the symmetric static Nash equilibrium g^N. Recall that the country is small (it cannot influence the world price ratio p). Thus the social optimum g^{so} is the solution of the problem

$$\max_{g_i} \frac{y(p, ng_i)}{c(p,1)} - D(g_i)$$

This yields the necessary condition

$$\frac{y_G(p, ng^{so})}{c(p,1)} - \frac{1}{n}D'(g^{so}) = 0 \tag{15}$$

Since the curve $(1/n)D'(g)$ is everywhere below the curve $D'(g)$, the solution g^N of equation (13) is smaller than the solution g^{so} of equation (15).

Example 1 (continued): Consider a small open economy that takes p as given.Using (9) and (10), we obtain from (13) and (15)

$$g^{so} = n\left(\frac{1}{c(p,1)}\right)\left(\frac{1}{1+\varepsilon}\right)(p)^{1+\varepsilon} = ng^N = n\left(\frac{1}{\Omega}\right)\left(\frac{1}{1+\varepsilon}\right)(p)^{1-\alpha+\varepsilon} \tag{16}$$

Now compare two countries with different cultures. In one country, say country X, everyone adopts the static Nash behaviour. In the other country, say country Y, everyone adopts an "Optimistic Behaviour," and contributes an amount $\widehat{g}$ where

$$g^N < \widehat{g} \leq g^{so}$$

where the difference $\widehat{g} - g^N$ is a measure of the degree of optimism. (We will later explain how such optimism is consistent with rational behaviour).

Then, at any given p, country Y will supply more apples (and less bananas) than country X. That is, country Y's relative supply of apples (Q_A^Y/Q_B^Y) exceeds that of country X. The relative demands of apples (C_A/C_B) are identical across all individuals. It follows that country Y will be exporting apples and importing bananas. Thus we have proved the following result:

Proposition 1: The country that adopts "the most Optimistic Behaviour" will be, in the long-run steady state, the net exporter of the environment-sensitive good.

Remark (Example 1, continued): For a country, say country X, where all individuals adopt static Nash Behaviour and behave as if they have no influence on price, the autarkic equilibrium price can be obtained by solving the following two simultaneous equations

$$p^{AU,X} = \left\{ \frac{(1+\varepsilon)\alpha E}{\left[(1-\alpha)+\varepsilon\right] G^X} \right\}^{1/(1+\varepsilon)}$$

where $G^X = ng^{N,X}$and

$$g^{N,X} = \left(\frac{1}{\Omega}\right)\left(\frac{1}{1+\varepsilon}\right)\left(p^{AU,X}\right)^{1-\alpha+\varepsilon}$$

Thus

$$p^{AU,X} = \left[\frac{(1+\varepsilon)^2 \alpha E \Omega}{\left[(1-\alpha)+\varepsilon\right] n} \right]^{1/(2-\alpha+2\varepsilon)}$$

Comparing with country Y where everyone adopts the most optimistic behaviour with $\widehat{g} = g^{so}$, we have

$$p^{AU,Y} = \left\{ \frac{(1+\varepsilon)\alpha E}{\left[(1-\alpha)+\varepsilon\right] G^Y} \right\}^{1/(1+\varepsilon)}$$

where $G^Y = ng^{so,Y}$

$$g^{so,Y} = n\left(\frac{1}{\Omega}\right)\left(\frac{1}{1+\varepsilon}\right)\left(p^{AU,Y}\right)^{1-\alpha+\varepsilon}$$

$$p^{AU,Y} = \left[\frac{(1+\varepsilon)^2\alpha E\Omega}{\left[(1-\alpha)+\varepsilon\right]n^2}\right]^{1/(2-\alpha+2\varepsilon)} < p^{AU,X}$$

This confirms that Y has comparative advantage in apples.

5. A Static Model of Optimistic Behaviour

In this section we offer an explanation (in a static framework) of "Optimistic Behaviour" .A better explanation (in a dynamic setting) will be offered in the next section.

The explanation offered in this section is in terms of "non-Nash conjecture." (See, for example, the book by Cornes and Sandler.) Suppose that each individual i thinks that if he increases his contribution beyond the static Nash contribution, others will follow suite. Thus individual i does not takes g_j as given. Rather, he assumes that

$$g_j = g^N + \sigma_i(g_i - g^N) \equiv r(g_i)$$

where $\sigma_i \geq 0$ is called the "conjectural variation" of individual i. If $\sigma = 0$, we are back to the static Nash behaviour. If $\sigma = 1$, we find that individuals will choose the social optimal contribution g^{so}.

6. A Dynamic Model of Optimistic Behaviour

This section draws on the work of Benchekroun and Long (2004).

The static model in section 3 is now extended to a dynamic setting, in which the assumption that capital K and land T are constant is maintained. The only source of dynamics is that each individual constructs an index of the social history of trust and reciprocity. This index is denoted by $S(t)$ and is assumed to evolve according to the following differential equation

$$\dot{S}(t) = \left[G(t) - ng^N\right] - \delta S(t)$$

where

$$G(t) = \sum_{i=1}^{n} g_i(t)$$

is the total contribution of all individuals in the country at time t and $S(0) = S_0$ is given The terms inside the square brackets measures the extent to which the contribution exceeds the static Nash contribution. If this term is positive, it leads to an increase in the state variable $S(t)$. The parameter $\delta > 0$ is the rate of decay of the state variable. (This reflects memory losses, for example.)

6.1. Main Results

Each individual seeks to maximize the integral of his own discounted utility flow:

$$\int_0^\infty e^{-\rho t}\left[\frac{y(p, G_{-i}(t) + g_i(t))}{c(p,1)} - D(g_i(t))\right] dt \tag{17}$$

subject to

$$\dot{S}(t) = \left[G_{-i}(t) + g_i(t) - ng^N\right] - \delta S(t) \tag{18}$$

We are looking for symmetric Markov perfect equilibria of this game.These equilibria are defined as follows. A (stationary) Markovian strategy μ_i for player i is a function μ_i that specifies for each value of S a contribution level g_i. Applying strategy μ_i means that agent i chooses his contribution g_i according to the time-invariant feedback law $g_i(t) = \mu_i(S(t))$. A strategy profile is an n-tuple of Markovian strategies, one for each agent. A strategy profile $(\mu_1, \mu_2, ..., \mu_n)$ is called symmetric if$\mu_i = \mu_j$ holds for all i and j. A strategy profile is a Markov perfect Nash equilibrium if for all S and all i the following is true: the optimal control problem of maximizing (17) subject to (18) and $g_j(t) = \mu_j(S(t))$ has an optimal solution which satisfies $g_i(t) = \mu_i(S(t))$.

Proposition 2: The strategy profile

$$\mu_i(S) = g^N$$

for all i (i.e. all agents make their static Nash contributions, and ignore any relevance of S) is a symmetric Markov perfect equilibrium of the differential game.

Proof: Obvious

The equilibrium depicted in Proposition 2 is a rather trivial one. We are now looking for non-trivial symmetric Markov perfect equilibria. Equilibria with Symmetric strategy profiles satisfying $\mu'(S) > 0$ are called **optimistic-behaviour strategy profiles,** and those with $\mu'(S) < 0$ are called **pessimistic-behaviour strategy profiles**. In this section, we focus on the optimistic behaviour.

Write the Hamiltonian function for problem (17):

$$H = \frac{y(p, G_{-i}(t) + g_i(t))}{c(p,1)} - D(g_i(t)) + \psi(t)\left[G_{-i}(t) + g_i(t) - ng^N - \delta S(t)\right]$$

Player i assumes that all players $j \neq i$ use the strategy $\mu(S)$. (We will characterise the equilibrium $\mu(S)$ later.) Then, letting $m = n - 1$,

$$H = \frac{y(p, m\mu(S(t)) + g_i(t))}{c(p,1)} - D(g_i(t)) + \psi(t)\left[m\mu(S(t)) + g_i(t) - ng^N - \delta S(t)\right]$$

The optimality conditions for player i are:

$$\frac{\partial H}{\partial g_i} = \frac{y_G(p, m\mu(S(t)) + g_i(t))}{c(p,1)} - D'(g_i(t)) + \psi_i(t) = 0$$

$$\dot{\psi}(t) = \psi(t)\left[\rho + \delta - m\mu'(S)\right] - \frac{y_G(p, m\mu(S(t)) + g_i(t))}{c(p,1)}\left(m\mu'(S)\right) \tag{19}$$

The transversality condition is

$$\lim_{t\to\infty} \psi(t)e^{-\rho t}S(t) = 0.$$

Thus (omitting the time argument)

$$\psi = -\frac{y_G(p, m\mu(S) + g_i)}{c(p,1)} + D'(g_i) \tag{20}$$

Differentiating (20)

$$\dot{\psi} = -\frac{y_{GG}(p, m\mu(S) + g_i)\left[m\mu'(S)\dot{S} + \dot{g}_i\right]}{c(p,1)} + D''(g_i)\dot{g}_i \tag{21}$$

Substituting (20) and (21) into (19) to obtain:

$$-\frac{y_{GG}(p, m\mu(S) + g_i)\left[m\mu'(S)\dot{S} + \dot{g}_i\right]}{c(p,1)} + D''(g_i)\dot{g}_i =$$

$$\left[-\frac{y_G(p, m\mu(S) + g_i)}{c(p,1)} + D'(g_i)\right][\rho + \delta - m\mu'(S)] - \frac{y_G(p, m\mu(S(t)) + g_i(t))}{c(p,1)}(m\mu'(S)) \tag{22}$$

In a symmetric equilibrium, we have $g_i = \mu(S)$ and thus $\dot{g}_i = \mu'(S)\dot{S}$. Substituting these into (22) we get

$$-\frac{y_{GG}(p, n\mu(S))\left[n\mu'(S)\dot{S}\right]}{c(p,1)} + D''(\mu(S))\mu'(S)\dot{S} =$$

$$\left[-\frac{y_G(p, n\mu(S))}{c(p,1)} + D'(\mu(S))\right][\rho + \delta - m\mu'(S)] - \frac{y_G(p, n\mu(S))}{c(p,1)}(m\mu'(S)) \tag{23}$$

Substituting $n\mu(S) - ng^N - \delta S$ for $\dot{S}$ in the above equation, we obtain a first order differential equation

$$\left[D''(\mu(S)) - \frac{y_{GG}(p, n\mu(S))n}{c(p,1)}\right]\mu'(S)\left(n\mu(S) - ng^N - \delta S\right) =$$

$$\left[D'(\mu(S)) - \frac{y_G(p, n\mu(S))}{c(p,1)}\right][\rho + \delta - m\mu'(S)] - \frac{y_G(p, n\mu(S))}{c(p,1)}(m\mu'(S)) \tag{24}$$

Solutions to this first order differential equations are potential candidates for symmetric Markov-perfect strategy profiles.Instead of solving this general differential equation, let us assume the specific functional form (11). Then the differential equation (24) becomes simply

$$\mu'(S)\left(n\mu(S) - ng^N - \delta S\right) = \left[\mu(S) - \left(\frac{1}{c(p,1)}\right)\left(\frac{1}{1+\varepsilon}\right)(p)^{1+\varepsilon}\right][\rho+\delta] - m\mu(S)\mu'(S) \tag{25}$$

Then, using (14), the differential equation (25) can be written as

$$\left(ng - ng^N - \delta S + mg\right)\frac{dg}{dS} = (g - g^N)(\rho + \delta)$$

or

$$\frac{dg}{dS} = \frac{(\rho+\delta)(g - g^N)}{ng - ng^N - \delta S + mg} \tag{26}$$

The differential equation (26) can be solved diagramatically. In Figure 1, we measure S along the horizontal axis and g along the vertical axis.

One solution is $g(S) = g^N$ (independent of S). Then $dg/dS = 0$. The horizontal line $g = g^N$ in Figure 1 depicts this solution.In a society where everybody thinks that nobody cares about the index of trust S, everyone will just choose the static Nash contribution g^N.

To construct other solution, let us draw in the positive orthant the line SS defined by

$$g = g^N + \frac{\delta}{n}S$$

Along this curve, we have $\dot{S} = 0$. Starting at any point on this line with $g > g^N$, the sign of dg/dS is positive.

Next, draw the line RR defined by

$$g = \frac{n}{n+m}g^N + \frac{\delta}{n+m}S$$

Along this line, the denominator of the right-hand side of (26) is zero. The integral curves must have infinite slope when they cut this line.

In Figure 1, the line $g = g^N$ and the line RR define four regions, denoted in roman numbers I, II, III, and IV. Only the integral curves in region II are meaningful candidates for symmetric Markov-perfect strategy profiles. We focus on candidates that lead to a steady state so that the transversality condition is satisfied.Thus we must restrict attention to the section of integral curves that cut the line SS from above. Two such curves are depicted in Figure 1, with two different steady states, S_K^L and S^*. The dark integral curve is tangent to the line SS at S^*. All values of S between 0 and S^* are possible steady states that are stable. The point S_K^H in Figure 1 is an unstable steady state. Thus we have proved the following results:

Proposition 3: There are infinitely many symmetric equilibrium paths, each leading to a steady state where the voluntary contribution to the public good is greater than the static Nash contribution.

An interesting question to ask is: can the social optimal contribution g^{so} be reached as a steady state contribution if agents use symmetric Markov-perfect strategies? To answer this question, re-write equation (24) as

$$\left[D''(g) - \frac{y_{GG}(p, ng)n}{c(p,1)}\right]\left(ng - ng^N - \delta S\right)\frac{dg}{dS} =$$

$$\left[D'(g) - \frac{y_G(p, ng)}{c(p,1)}\right][\rho + \delta] - D'(g)\left(m\frac{dg}{dS}\right) \tag{27}$$

At a steady state, $ng - ng^N - \delta S = 0$, and we obtain

$$0 = \left[D'(g) - \frac{y_G(p, ng)}{c(p,1)}\right][\rho + \delta] - D'(g)\left(m\frac{dg}{dS}\right)$$

At $g = g^{so}$, we have

$$D'(g^{so}) = \frac{ny_G(p, ng)}{c(p,1)}$$

Hence

$$(n-1)\frac{y_G(p,ng)}{c(p,1)}[\rho+\delta] = \frac{ny_G(p,ng)}{c(p,1)}\left(m\frac{dg}{dS}\right)$$

Thus, at $g = g^{so}$

$$\frac{dg}{dS} = \frac{\rho+\delta}{n} > \frac{\delta}{n}$$

It follows that g^{so} cannot be a stable equilibrium, because the slope dg/dS exceeds the slope of the line SS.

Proposition 4: For all $\rho > 0$, the social optimal contribution cannot be reached as a stable steady state. If ρ is arbitrarily close to zero, the social optimum g^{so} can be closely approximated by the long run equilibrium contribution of a symmetric Markov perfect strategy profile.

6.2. An analytical solution

Recall the differential equation (26)

$$\frac{dg}{dS} = \frac{\left[g-g^N\right](\rho+\delta)}{mg+(ng-ng^N-\delta S)} \tag{28}$$

We obtain the following "inverted" first order differential equation:

$$\frac{dS}{dg} = \frac{(m+n)\,g-\delta S-ng^N}{\left[g-g^N\right](\rho+\delta)} \tag{29}$$

Let $a = \frac{\delta}{(\rho+\delta)}$, $b = \frac{(m+n)}{(\rho+\delta)}$,$B = \frac{m}{(\rho+\delta)}$and $z = g - g^N$. The equation (29) can be written in the form (see Appendix):

$$\frac{dS}{dz} + \frac{aS}{z} = b + \frac{Bg^N}{z} \tag{30}$$

The family of solutions is:

$$S\,(z) = \frac{bz}{1+a} + \frac{Bg^N}{a} + z^{-a}K \tag{31}$$

For each K, (31) defines an implicit relationship between z (or g) and S. (Note: for $K = 0$ we have a linear solution). Given K, expressing S as a function of g for $g > g^N$, we have

$$S_K(g) = \frac{b(g - g^N)}{1 + a} + \frac{Bg^N}{a(1 + a)} + K(g - g^N)^{-a} \tag{32}$$

We show in the appendix that stable solutions can only be obtained by setting $K < 0$. Furthermore, there exists a unique value $K^* < 0$ such that for all K in the interval $(K^*, 0)$ the corresponding strategy profile

$$\mu(S) = S_K^{-1}(S)$$

is a Markov-perfect equilibrium.

If $K = K^*$, the equilibrium contribution will approach the corresponding steady state g^*, and we can show that

$$g^N < g^* < g^{s0}$$

and

$$\lim_{\rho \to 0} g^* = g^{so}$$

Thus, we have confirmed that that there is a continuum of Markovian Nash equilibrium, each giving rise to a path converging to a steady state at which public good contribution is greater than the static Nash equilibrium level, but is still below the social optimum, and if the rate of discount ρ is close enough to zero, then it is possible to approximate the social optimum.

To summarize, there is maximum level of contribution to the public good g^* (and a corresponding stock of social environment $\widehat{S}_{K^*}$) that can be supported as the steady state level of contribution to the public good a Markovian Nash equilibrium. Although g^* is smaller than the socially optimal level of contributions to the public good g^{so} (and $\widehat{S}_{K^*} < S^{so}$) it is larger than the level of g^N the contributions to the public good under the static Nash equilibrium (and $\widehat{S}_{K^*} > S^N = 0$).

The steady state level of contribution to the public good g^* is supported by a Markovian Nash equilibrium where the equilibrium contribution strategy is an increasing function of the stock of social environment. When agent i takes the contribution of agent $j \neq i$ as given, he can still influence the amount contributed at each moment by agent j by influencing the level of the stock of social environment. This feedback effect increases the marginal benefit of the contribution to the public good and the resulting equilibrium level of contributions exceeds the contribution level under the static Nash equilibrium where the feedback effect is absent.

7. The effects of the opening of trade on export status and welfare

Recall the assumption that all countries are small and take the terms of trade as given. The equation (16) tells us that the social optimum contribution g^{so} is an increasing function of the world price p^W.

First, consider a country that starts at a Pareto Optimum under autarky:

Consider a country (say the home country) that begins with autarky, and in which all individuals contribute exactly the amount their social planner would wish (i.e. $K = K^*$, ρ is very close to 0 and the steady state is already reached.). They are at a Pareto optimum (given autarky). Suppose their autarkic price is p^{AU} and the contribution level is g^{so}. The autarkic price and the social optimal contribution can be obtained from the two equations (7) and (16), which must be solved **simultaneously**

$$p^{AU} = \left\{ \frac{(1+\varepsilon)\alpha E}{\left[(1-\alpha)+\varepsilon\right] n g^{so}} \right\}^{1/(1+\varepsilon)}$$

and

$$g^{so} = n \left(\frac{1}{\Omega}\right) \left(\frac{1}{1+\varepsilon}\right) \left(p^{AU}\right)^{1-\alpha+\varepsilon}$$

Thus, for this country,

$$p^{AU} = \left[\frac{(1+\varepsilon)^2 \alpha E \Omega}{[(1-\alpha)+\varepsilon]\, n^2}\right]^{1/(2-\alpha+2\varepsilon)}$$

Suppose $p^{AU} < p^W$ (the world price). Then the home country has comparative advantage in the environment-sensitive good (apples). With the opening of trade, the country will export apples, and increase the public good contribution level.

If $p^{AU} > p^W$ (this can happen if countries are not identical in technology etc.), then the home country has comparative advantage in good B. The opening of trade will lead to home country to reduce g^{so}. But this **does not mean** the country is worse off under free trade. After all, if apples can be imported at a low price, the country should not invest too much in a public input that serves to raise the productivity of apple-producing firms. (A higher level of public good does not mean "better", because contribution is not costless.)

Now, consider the case where a country does not start at a Pareto Optimum (e.g. $K > K^*$). If S_0 is below the free-trade steady state, the country will accumulate S and it may change its status in the process of such accumulation. It may begin as an importer of apples, and end up as an exporter of apples, because G will be growing over time. Suppose S_0 is at its autarkic equilibrium level, and under free-trade, given K, the free-trade steady state S_∞ is greater than S_0. Can we prove that the country's welfare under free trade is higher than under autarky? This would require integrating the utility flow along the adjustment path. The answer is not at all obvious.

8. Concluding remarks

We have shown that small open economies with identical endowment, technology, and preferences can have different trade patterns, depending on how a public productive input (e.g. the quality of the environment) is supplied by individuals in the economy. In some economies, individuals may adopt static Nash behaviour, and this results in a (static) Nash equilibrium supply of the public good. In other economies, each individual expects that other individuals in the economy use a behavior rule that conditions their public good contribution on the level of trust in the society, and consequently he has an incentive to build up the social level of trust. This can result in behavior rules that lead to a higher level of public good and superior performance in terms of welfare at any given world relative price. These economies will have comparative advantage in the production of the environment-sensiive good. If the rate of discount is small enough, the steady state of economies with non-static Nash-behaviour can approximate what a fictitious social planner for their economies would want to achieve.

Our model provides a theoretical support to Arrow's hypothesis that in some societies each individual is, in some ultimate sense, motivated by purely egoistic satisfaction derived from the goods accruing to him, but there is an implicit social contract such that each performs duties for the other in a way calculated to enhance the satisfaction of all.

It is important to note that in our model the variable that represents social history is not an argument of the utility function nor is it a stock from which a good (public or private) can be extracted. In fact, this variable has "no intrinsic value". A remarkable feature of our model is that a variable of no intrinsic value can influence behavior and improve welfare even when individuals do not resort to trigger strategies.

APPENDIX 1

The numerator of (29) can separated to obtain

$$\frac{dS}{dg} = \frac{(m+n)\left(g-g^N\right)+mg^N}{\left[g-g^N\right](\rho+\delta)} - \frac{\delta S}{\left[g-g^N\right](\rho+\delta)}$$

Thus

$$\frac{dS}{dg}+\frac{\delta S}{(g-g^N)(\rho+\delta)}=\frac{\left(g-g^N\right)(m+n)}{(g-g^N)(\rho+\delta)}+\frac{mg^N}{(g-g^N)(\rho+\delta)}$$

Substituting $a=\frac{\delta}{(\rho+\delta)}$, $b=\frac{(m+n)}{(\rho+\delta)}$,$B=\frac{m}{(\rho+\delta)}$and $z=g-g^N$ yields (30).

APPENDIX 2

For $K<0$, and $g>g^N$, $S_K(g)$ is a strictly concave and increasing function, with $\lim_{g\to g^N}S_K(g)=-\infty$ and $\lim_{g\to\infty}S_K(g)=\infty$. For $K>0$, and $g>g^N$, $S_K(g)$ is a strictly convex function, with $\lim_{g\to g^N}S_K(g)=+\infty$ and $\lim_{g\to\infty}S_K(g)=+\infty$. Furthermore, $\lim_{g\to g^N}S'_K(g)=-\infty$ and $\lim_{g\to\infty}S'_K(g)=b/(1+a)$. We must determine whether the curve $S_K(g)$ intersects the curve $S=n(g-g^N)/\delta$ for $g>g^N$. If an intersection exists, it is a steady state.

Steady states are denoted (with a hat) by $\widehat{g}=g^N+(\delta/n)\widehat{S}$. They are implicitly determined by

$$\widehat{S}=\frac{b}{1+a}\left((\delta/n)\widehat{S}\right)+\frac{Bg^N}{a}+\left((\delta/n)\widehat{S}\right)^{-a}K$$

Let

$$\eta\equiv(\frac{b}{1+a})(\frac{\delta}{n})-1<0$$

then

$$\eta\widehat{S}+\frac{Bg^N}{a}=-K\left((\delta/n)\widehat{S}\right)^{-a}\tag{33}$$

The left-hand side of (33) is linear and decreasing in $\widehat{S}$ and is positive for $\widehat{S}\in(0,Bg^N/(-\eta a)$ and negative for $\widehat{S}>Bg^N/(-\eta a)>0$. There are three cases: $K>0, K=0$ and $K<0$.

CASE 1 : $K>0$

For any positive K, the right-hand side of (33) is a negative and increasing function of $\widehat{S}$ for all $\widehat{S}>0$. It follows that for each positive

K, there exists a unique value of $\widehat{S}$, denoted by $\widehat{S}_K$, which satisfies (33). That $\widehat{S}_K$ is greater than $Bg^N/(-\eta a)$ and is unstable, because, in a diagram with g measured along the horizontal axis, the curve $S_K(g)$ cuts the curve $S = n(g - g^N)/\delta$ from below.

A formal proof of instability:

Stability requires (when $\frac{dS}{dz} > 0$) that, evaluated at the steady state $\widehat{S}_K$

$$\frac{dS}{dg} = b\left(\frac{1}{1+a}\right) - aK\left(\delta S - g^N\right)^{-a-1} \geq \frac{n}{\delta}$$

For $K > 0$, this condition is satisfied if

$$b\left(\frac{1}{1+a}\right) - \frac{n}{\delta} > aK\left(\delta S - g^N\right)^{-a-1}$$

But this is not possible, because the right-hand side is positive for $K > 0$, and the left-hand side is negative given that $\eta < 0$.

CASE 2: $K = 0$

In this case, there exists a unique steady state, $\widehat{S}_K = Bg^N/(-\eta a)$. It is unstable.

CASE 3: $K < 0$.

For any negative K, the right-hand side of (33) is a positive, convex, and decreasing function of $\widehat{S}$ for all $\widehat{S} > 0$. It follows that if the absolute value of K is not too large, the convex curve must intersect the downward sloping straight-line that represents the left-hand side of (33) exactly twice, at values which we denote by S_K^L and S_K^H where

$$Bg^N/(-\eta a) > S_K^H > S_K^L > 0.$$

It is clear that S_K^L is locally stable and S_K^H is unstable. This is because the function $S_K(g)$ is concave, and thus the curve representing it in the space (g, S) (with g measured along the horizontal axis) cuts the line $S = n(g - g^N)/\delta$ from below at the point S_K^L and from above at the point S_K^H.

There is a critical value of K, denoted by K^* such that for all K smaller (larger in absolute value) than K^* the convex and decreasing curve that represents the right-hand side of (33) does not intersect the downward sloping straight-line that represents the left-hand side of (33). If $K = K^*$, we have $S^H_{K^*} = S^L_{K^*}$, that is, the steady state is unique. We will denote this unique steady state by $\widehat{S}_{K^*}$. Let $g^* = g^N + (\delta/n)\widehat{S}_{K^*}$ be the associated steady state level of contribution to the public good.

To find K^*, we note that the curve $S_{K^*}(g) = \frac{b(g-b^N)}{1+a} + \frac{Bg^N}{a} + K^*(g-g^N)^{-a}$ must be tangent to the line $S = n(g-g^N)/\delta$ at the unique steady state value $\widehat{S}_{K^*}$. Thus

$$S'_{K^*}(g^*) = \frac{b}{1+a} - aK^*\left[\frac{\delta\widehat{S}_{K^*}}{n}\right]^{-a-1} = \frac{n}{\delta} \tag{34}$$

Hence

$$-\frac{a\delta}{n}K^*\left[\frac{\delta\widehat{S}_{K^*}}{n}\right]^{-a-1} = 1 - \frac{b}{1+a}\left(\frac{\delta}{n}\right) = -\eta \tag{35}$$

On the other hand, by definition of a steady state,

$$\eta\widehat{S}_{K^*} + \frac{Bg^N}{a} = -K^*\left(\frac{\delta\widehat{S}_{K^*}}{n}\right)^{-a} \tag{36}$$

Using (35) and (36) to eliminate K^*

$$\frac{a\delta}{n}\left[\eta\widehat{S}_{K^*} + \frac{Bg^N}{a}\right] = -\eta\left(\frac{\delta\widehat{S}_{K^*}}{n}\right)$$

Solving for $\widehat{S}_{K^*}$

$$\widehat{S}_{K^*} = \frac{Bg^N}{(-\eta)(1+a)} > \left(\frac{ng^N}{\delta}\right) \tag{37}$$

Having determined $\widehat{S}_{K^*}$, we can use (37) and (36) to solve for K^*.

It follows that

$$g^* - g^N = \frac{\delta B g^N}{n(-\eta)(1+a)} > 0$$

Now, we show that as $\rho \to 0$, $g^* \to g^{so}$.

$$\frac{g^N}{g^*} = \frac{n(\rho + 2\delta) - \delta\,[m+n]}{n(\rho + 2\delta) - \delta\,[m+n] + \delta m}$$

$$\lim_{r \to 0} \frac{g^N}{g^*} = 1 - \frac{m}{n} = \frac{g^N}{g^{so}}$$

Thus

$$\lim_{r \to 0} g^* = g^{so}$$

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Figure 1