RECONSIDERING PERFORMANCE AT THE SUMMER OLYMPICS AND REVEALED COMPARATIVE ADVANTAGE

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Abstract

This paper examines the performance of the participating countries at the Summer Olympic games. It investigates each country's performance and attempts to identify the determinants of this performance in each sport, and also examines other issues related to specialization at these games, using the concept of revealed comparative advantage (RCA) developed in the field of international economics. Each country's RCA is explained by geographical, biological as well as economic variables of the participating countries. Most previous studies investigated the correlation between total/per capita performance and a wide range of variables, using a range of methods that we consider to be inappropriate. A few studies employed more appropriate censoring methods, however, they did not consider heteroscedasticity or non-normality in their regressions that could make the estimates inconsistent. In addition, RCA and specialization in the Olympic games has never been analyzed. Our analyses present the determinants of each country's specialization in sports and the patterns of RCA, which are substantially different from those obtained when analyzing total and per capita performance. We also found that high-income countries specialize less; in other words, they win medals in a more diversified range of sports, which is analogous to a country's patterns of specialization in production, a topic frequently explored in international economics.

1. INTRODUCTION

The Olympics are no longer purely a showcase for the Olympic ideals of peace and international friendship of all mankind made manifest through participation in the games. The Olympic Games are also the markets where each country produces medals by investing resources, in order to demonstrate its national power and competency. In 2000, the citizens of more than 200 nations, after sending 10,200 athletes to the market (Sydney), consumed and enjoyed commodities (or services) produced, which represent 'performance' or, more specifically, 'the number and colour of medals'.

Becker (1976) argued that what most distinguishes economics as a discipline from other disciplines in the social sciences is not its subject matter but its approach. Nevertheless, the Olympic Games have served as the subject matter of several disciplines, such as sport science, tourism, sociology or politics rather than economics.

This paper aims to explore the economics of the Olympic games, not in the sense of emphasizing the material aspects of the Games (such as revenue, expenditure and effects on the economies of the host cities). Rather, it provides an important but often overlooked aspect of the Games: an economic analysis of performance of the participating countries at the Summer Olympics. Special attention is paid to patterns of specialization or the concept of comparative advantage, as earlier investigated by Wallenchinsky (1996), who found a strong correlation between specific kinds of sports and the performance of each nation.

The next section reviews previous research on the performance of nations at the Olympic games, and discusses the shortcomings in these studies. Section three introduces data and outlines the methodology employed in the analysis. The results are discussed in section four. Section five summarizes the findings and proposes further areas where research is required.

2. PERFORMANCE OF NATIONS AT THE SUMMER OLYMPIC GAMES

Frequent attempts to quantify and analyze the relationship between a country's performance at the Olympic games and the determinants of this performance have been made in a variety of different fields. In these studies, the performance of a country was, in general, measured by the total number of medals, the number of gold medals, or by a points system that assigned different values to the number of gold, silver and bronze medals won. For example, Ball (1972) assigned three, two and one point(s) to each medal color. These analyses can be classified into two categories, mainly depending on the method they used: the correlation approach analysis (for example, Ball, 1972; Novikov and Maximenko, 1972; Levine, 1974, Pooley, Shaw, Hare and Promoli, 1975) and the regression method (for example, Grimes, Kelly and Rubin, 1984; Gartner, 1989; Bernard and Busse, 2000).

The first group investigated the correlation between the performance of each country and a wide range of variables. They generally reported that a country's overall performance is highly correlated with a wide range of variables including economic, demographic, social and political variables.

In the 1980's, as social scientists made strenuous efforts to discover the determinants of national Olympic success, regression methods were more intensively used. Most of the studies in this group found that economic and demographic variables played important roles in determining the level of performance for each country. For example, Gartner (1989), using the OLS method, showed that population, GNP, and GNP per capita are, in general, very significant. He also confirmed the out-performance of socialist countries. However, as Gartner (1989) confessed in his study, OLS is not an appropriate method of analysis. Given that the dependent variables used are 'performance' or 'medal tally', it should be treated as a censored model where the lower limit of the dependent variable is zero. Grimes et al. (1984)

is one of few studies that used tobit to analyze Olympic performance. They employed population, GNP and communist dummy variables to explain the overall performance of nations at the 1972 Summer Olympics, and showed that all the independent variables were significant (at the 1% level) determinants of performance. Significant contributions in this field were made, at least in terms of methodology, by Baimbridge (1998) and Bernard and Busse (2000). Baimbridge (1998) used regression analysis based on logistic transformation of the dependent variable to discuss uncertainty in the outcome of the Olympic Games, and Bernard and Busse (2000) used panel data drawn from the Summer Olympic games held over 30 years and, from probit and tobit analyses, found that a country's per capita GDP, population, the previous year's performance and some dummy variables are all significant determinants of a country's performance.

Most of these two groups of studies, in general, found that GNP, per capita GNP, population, and some non-economic variables such as 'the communist bloc', adequately explain a nation's performance. These findings are intuitively appealing; however, two things should be reconsidered. First, it is questionable whether the finding that a country with more economic power and a larger population, in general, collects a larger number of medals at the Olympics adds anything new to what has already been established. If the distribution of athletic ability among people does not differ significantly across countries, it is logical that a country with a large population will have a greater number of talented athletes than a country with small population. Also, a higher level of GDP (or per capita GDP), in general, tells us that the country, at least potentially could afford to invest a larger amount in sport.

The second concern with previous research centers on the methodology used. At every Olympic games, a considerable number of countries wins only a few medals or none at all. The results from studies utilizing the OLS method, therefore, have serious problems such as inconsistency, due to the prevailing existence of censored observations (Greene, 1993). In

contrast, the tobit method does not waste information about the dependent variable (especially when it is zero), and does not yield predicted values, which fall below the lower limit of the dependent variable. As discussed already, Grimes et al. (1984) is one of few studies that have employed an appropriate estimation method. Even their model, however, did not consider heteroscedasticity or non-normality at all, which is frequently observed in limited dependent variable models (Greene, 1993). Therefore, the maximum likelihood estimator obtained by them using tobit could be inconsistent and/or inefficient.

With the shortcomings in the previous research in mind, this study attempts to apply comparative advantage theory using tobit analysis to explain the performance of each country at the summer Olympic games, which has never been done previously. We hope that the results of or research will enhance our understandings of the economic features of performance at the Summer Olympics as well as reveal new insights into explanations for countries' patterns of specialization.

The next section presents alternative approaches that we adopted in our analysis of each nation's performance. It also discusses variables, with a special focus on revealed comparative advantage in sports competition, and reports the source of data used in this study.

3. METHODOLOGY AND DATA SOURCE

Neoclassical Trade Models and Olympic Performance

This paper aims to explore some aspects of the participating countries' Olympic performance and, more specifically, investigates issues related to revealed comparative advantage (RCA) in the Summer Olympic Games. In this section we apply neoclassical trade theories to discuss the issues related to RCA.

As is well known, neoclassical trade theory explores the relationship between the relative endowments of factors, the relative factor intensity (or contents) of commodities, and the patterns of trade. It has been developed from the two-factor two-good model, to a general model with the n-factor and m-good (such as the Vanek-Bertrand model). Incorporating some regular assumptions adopted by neoclassical economics, the theory predicts that trade leads a country into specialization according to its relative factor endowment and the factor intensity of its commodities. In practice, when researchers examined the neoclassical trade model, a certain kind of index was needed to represent the degree of comparative advantage or patterns of trade. For this purpose, the concept of RCA has received wide attention (for example, see Balassa, 1965; Heller, 1976; Leamer and Bowen, 1981; Bowen, 1983; Leamer, Bowen and Sweikauskas, 1987; Yeats, 1989; Lafay, 1993). The concept of RCA pertains to the relative trade performances of individual countries in particular commodities, and is based on the assumption that the commodity pattern of trade reflects inter-country differences in relative costs, as well as in non-price factors (Balassa, 1965).

The application of RCA to the performance of countries participating at the Olympics reveals useful information about the patterns of specialization in sport, although the goods (medals) produced are not traded.[1] Each country participating at the Olympic Games is endowed with a limited amount of resources to invest in sports competition. In order to maximize the number of medals that it can win, each country concentrates on the sport in which it has a comparative advantage. For example, in a simple two-factor (capital and labor) model, a developed country with a relatively large supply of capital but a small population would specialize in capital-intensive sports, such as yachting. In contrast, a poor country with a relatively low level of capital would specialize in those sports where capital is relatively less important (or labour-intensive), say marathon running or boxing.

In order to further expand our analysis and to interpret the results obtained, we need to identify some assumptions, which are generally adopted in neoclassical trade models.

[Assumption 1] *Medals of the same color provide the same level of utility.*

[Assumption 2] *Each country uses its resources to produce medals.*

[Assumption 3] *Countries share homogenous tastes and the production functions of medals is the same in all countries.*

[Assumption 4] *Factor intensity reversal in medal production does not occur.*

With these assumptions, the conventional estimation method in neoclassic al trade models applies to estimate country i's relative performance (revealed comparative advantage) in sport j as

$$R_{ij} = \sum_{k=1}^{n} b_{ijk} F_{ik} + u_{ij} \quad , \qquad (1)$$

where R_{ij} is country i's RCA index for sport j, F_{ik} is the relative level of resource k in country i, b_{ijk} is a coefficient indicating the impact of the relative level of resource k on country i's RCA in sport j, and u_{ij} is a residual.

The RCA index for country i in sport j is calculated as

$$R_{ij} = \frac{M_{ij}/M_i}{T_j/T}, \qquad (2)$$

where M_{ij} is the total number of medals country i wins from sport j, M_i represents the number of medals won by country i in all sports at the Summer Olympics, T_j is that assigned to sport

j, and T is the total number of medals available at the Summer Olympic Games. If $R_{ij} > 1$, it implies that this country performs relatively better in sport j than it is supposed to (in other words that it has RCA in sport j), and *vice versa*. Therefore, the country, which has neither RCA nor revealed comparative disadvantage (RCD) in any sport will have $R_j = 1$ for all $j = 1, 2, \ldots, N$.

Table 1 reports the RCA indexes for 66 countries in six groups of sports for the Summer Olympics.[2] As a measure of specialization, the RCA index demonstrates dramatic differences from the ranking of each country produced using total/per capita performance. Table 2 contrasts the performance (ranking) of selected countries at the Olympic Games by the three different measures – total performance, per capita performance and RCA. It demonstrates the extent to which the ranking of each country changes according to different measures of performance. For example, the United States is ranked first in athletics in total medals, fourth in per capita medals, but 20th in RCA. In contrast, Ethiopia is ranked 13th in athletics in total medals, 27th in per capita medals but first in RCA. It implies that the effects of the same independent variable should be different across different measures of performance.

Estimating Performance Using Revealed Comparative Advantage

Identity is the relationship between (a certain type of) RCA, factor endowment and factor intensity (or content), as discussed by Bowen and Leamer (1981). Therefore, from information on any two, the other can be inferred. In our estimation, however, the coefficients do not necessarily reflect the factor intensity with which a factor is used to produce RCA. Instead, they directly indicate how a country's RCA index in a specific sport changes as the country's relative endowments change. Our major concern is not to test or identify neoclassical trade models. Nor do we attempt to establish the relationships among factor

endowment, factor intensity and the patterns of specialization. Instead, we attempt to explore the patterns of specialization in sport, and to characterize and summarize the empirical relationship between RCA and various variables of particular interest.

We do not have any observation for the dependent variable (performance) below the threshold (in this case zero), as it is impossible for a nation to have a negative performance at the Olympic Games. Therefore, as discussed, a censored regression model, in particular, the standard tobit model (or Type I tobit by Amemiya, 1985) is the most proper model to use. Unlike the estimators from the least squares method that always tend to overestimate the real parameters for this kind of data, the maximum likelihood (ML) estimators by tobit are consistent (Maddala, 1987), and the ML function for the tobit model has a single maximum (Amemiya, 1973).

The relationship between RCA at the Olympics and factor endowments is estimated using the following equation (3), which is based on equation (1) and considers dummy variables as well.

$$\mathbf{R_{ij}}^{*} = c + \alpha'\mathbf{X_i} + \beta'\mathbf{Y_i} + \gamma'\mathbf{D_i} + \varepsilon_i \qquad (3)$$

$$\begin{array}{lll} \text{where} & R_{ij} = 0 & \text{if} \quad R_{ij}^{*} \leq 0 \\ \text{and} & R_{ij} = R_{ij}^{*} & \text{if} \quad R_{ij}^{*} > 0. \end{array}$$

R_{ij} is the RCA index observed for country i in sport j, $\mathbf{X_i}$ and $\mathbf{Y_i}$ are vectors of the relative endowments of economic and natural environment resources for country i and $\mathbf{D_i}$ is a dummy vector. c is a constant, α, β and γ are parameter vectors to be estimated, and ε_i is assumed to be normally distributed with $N(0, \sigma^2)$.

GNP per capita, as well as GNP and population are included in vector **X**. GNP per capita is used to capture the effect of relative capital or wealth, and GNP and population to find scale effects. Each country's 'absolute' performance (such as total medals and per capita

medals) and comparative advantage will be based on many factors in addition to a variety of economic variables. The natural environment, although mostly constant over time, contributes to a country's performance at the Olympics (in the same way that its relative endowment shapes comparative advantage and specialization in a certain types of sport). For example, performance in beach volley ball probably would be related to the temperature and the length of coastline in a country as well as specific physical conditions, though it can be played indoors nowadays. Landmass, coastline, temperature and altitude are included in vector **Y**. Temperature deviation from 18 degrees Centigrade is included because different climates may influence the popularity of sports differently and also provide different training conditions, which will affect a country's performance in some sports. For similar reasons, altitude is also taken into consideration. These economic and environmental variables are divided by the average value of each variable and interpreted as the relative endowments of a particular country compared to the average country.

$\mathbf{D}_i$ is a vector of three dummy variables. Physical or biological attributes may be one of the most important factors determining a country's performance in sports competition, as explored by Khosla (1978, 1983). Unfortunately, it is difficult to collect and quantify all the nations' physiological attributes into a few variables. In consequence, a very wide classification by continents is used. For Asian and African countries, dummy variables are assigned as

$ASD_i = 1$ if country i is an Asian country
$= 0$ otherwise, and

$AFD_i = 1$ if country i is an African country
$= 0$ otherwise.

The use of dummy variables (for Asia and Africa) to capture the effects of physiological characteristics may be too broad to explain the different attributes of ethnic groups or races. Members of countries belonging to the same continent sometimes possess significantly different physiological characteristics, and some countries consist of various ethnic groups. However, we believe that this broad classification could capture the impacts of variables which are omitted due to data limitation, regardless of their significance, such as weight, height, and the intensity or flexibility of muscles of different nationalities. If they were available, it would make it easier to obtain more accurate results without any question.

Also, while we assume that nations share more or less the same goals, the size of a nation's sports budget as well as the intensity and collective efforts made (to win more medals to improve national pride and esteem through sports competition) will undoubtedly affect a country's performance at the Games. A large number of papers found the significant out-performance of the former Soviet or Eastern-European countries in international competition (eg, Grimes et al., 1974; Baimbridge, 1998; Bernard and Busse, 2000). In order to consider this phenomenon, a dummy variable for former (or current) socialist countries is assigned as

$$SCD_i = 1 \quad \text{if country i is a former or current socialist country}$$
$$= 0 \quad \text{otherwise.}$$

In estimating equation (3), we classify sports in the Summer Olympics into six groups: swimming, athletics, weight games, ball games, gymnastics, and others. This level of disaggregation may not be sufficient, in particular when investigating RCA. For example, in our study, the high jump and the marathon are placed in the same group (athletics) and soccer and table tennis are placed in the same group (ball games). Even though this level of

disaggregation has rarely been previously attempted, our study is still analogous to using, say, 2-digit SITC (standard international trade classification) data to analyze trade patterns, which is probably 'still too general' and may require a greater degree of disaggregation. Two main reasons explain why we relied on this rather general classification of sport. First, to disaggregate further, would require more information on how to recategorize different or similar kinds of competition. For example, it is not clear whether in swimming the 1,500M free style and the 100M butterfly should be categorized into the same group or not. Second, if we were to disaggregate the data further, we would end up with considerably more zeros for the dependent variables. This would make it difficult to interpret the outcome of our analysis. Table 3 summarizes how many medals are available for each group of sports in the three summer Olympics from 1988 to 1996.

Due to the existence of various RCA indexes, there have been intensive debates on the consistency among them (for example, Webster, 1991; Balance et al., 1987). They concluded that different cardinal RCA indexes tend to provide inconsistent results while ordinal ones are relatively consistent. The ranking of the RCA index is also used in this study to accommodate this argument and supplement the estimation using RCA indexes. The results of estimation are summarized and discussed in Appendix 1.

Data

In deriving dependent variables (RCS indexes), we used the cumulative number of medals for each country and sport obtained from three consecutive Summer Olympic games: Seoul (1988), Barcelona (1992), and Atlanta (1996). We did not include the data for the 1980 (Moscow) and 1984 (Los Angeles) games, since many countries did not participate in them and thus the distribution of medals was seriously distorted as Baimbridge (1998) has already pointed out. The medal tally data were collected from The Olympic Games (1999).

Economic and population data were obtained from International Financial Statistics (various years). All GDP data were converted into U.S. dollars using current exchange rates. We took an average of the 1988, 1992, and 1996 data, for every economic variable that we used. Geographical and environmental data such as average temperature, altitude, and coastline were obtained from web sites www.geographic.org by Photius Coutsoukis and Information Technology Associates (1999).

We were able to collect the necessary geographical and economic data for a total number of 66 countries. Of those, 62 won at least one medal during the three Olympic Games that we studied. Lists of all 66 countries examined in this study, former (or current) socialist countries, Asian countries and African countries, are provided in detail in Appendix 2.

4. RESULTS AND INTERPRETATION

Revealed Comparative Advantage and Olympic Performance - Results

When estimating equation (3), heteroscedasticity was frequently found. For the limited-dependent-variable models, as Maddala and Nelson (1975) showed, heteroscedasticity results in the estimators being neither consistent nor efficient. Hurd (1979) also reported, that in a truncated (or censored) regression model, heteroscedasticity caused the parameters to be estimated by a substantial bias. Therefore, it is essential to estimate the equation using heteroscedastic tobit once the residuals are found not to be orthogonal to independent variables. Consequently, except for gymnastics where heteroscedasticity was not found to be significant, heteroscedastic tobit was used to correct the heteroscedasticity by LIMDEP. The tobit model in LIMDEP specifies the heteroscedastic variance σ_i^2 as $\sigma_i^2 = \sigma^2 \exp[\delta' W_i]$,

where δ is a vector of coefficients and W_i is a vector of independent variables used to diagnose heteroscedasticity.

Table 4 reports the results of heteroscedastic tobit regression for various kinds of sport and performance, except gymnastics, where general Type I tobit is used. As is widely known, the estimators of tobit should not be understood as a direct partial relationship between the independent variable and the dependent variable. Instead, the results obtained from the tobit show the conditional expected value of the latent variable M^* with respect to an independent variable x_i such as

$$\frac{\partial E\left[M_i^* \mid x_i\right]}{\partial x_i} = \beta.^4$$

It is shown in Table 4 that the results are substantially different from the previous studies where GDP/per capita GDP and population were found to be significant explanatory factors. Each variable turns out to be significant for performance in at least one group of sport. For swimming, while relative endowments of economic or environmental variables are not significant, the Asian countries dummy is marginally significant (at the 10% level) and negative. This result implies that relatively, Asian countries did not perform well in swimming.[5] Countries with RCA in athletics are relatively well endowed with landmass, high altitude, high GDP per capita, and relatively less well endowed with coastlines. These findings are consistent with our expectations. In particular, it is noteworthy that the relative length of coastline provides a revealed comparative disadvantage in athletics. AFD also turns out to be significant and positive in athletics, indicating the relatively better performance of African countries than countries in the other continents. RCA in weight games are positively related to relatively high GDP. A country, which has either relatively hot or cold

temperatures (which is not suitable for many outdoor sports), is also found to have RCA in weight games. In contrast, a country which has higher altitude and higher GDP per capita has RCD in weight games. All the three dummy variables are also very significant for weight games. Former/current socialist countries did have RCD. This result reflects that their relative performance in weight games (relative to the other countries) is not so good as that in the total medal tally. Both Asian and African countries show strong RCA in weight games. These countries performed relatively better in weight games than non-weight games where the players are not restricted by their physical conditions such as height and weight. The RCA indexes in ball games and gymnastics are significantly affected by one variable each: total population and former/current socialist countries dummy respectively. A positive coefficient for former/current socialist countries indicates that they demonstrated superior performance in terms of RCA in gymnastics, as well as in terms of absolute performance.

It is noteworthy that some variables such as landmass, coastline and altitude, which were not significant in our preliminary analyses in explaining overall and per capita performance[6], become significant when the RCA index is used. These dramatic changes in the results suggest that an analysis based solely on overall or per capita performance reveals only a partial explanation. This is because results obtained solely from overall or per capita performance have the capacity to be misleading when in depth information and knowledge about the patterns of specialization or comparative advantage in sports competition is required.

RCA, Diversification and the Wealth of Nations

It is observed that countries have different degrees of specialization as well as different sports in which they specialize. This section examines which variables affect the degree of specialization.

Many empirical works assert that consumers spend their budget on more diversified goods as their income increases (for recent examples, see Chen, 1999). Considering that performance in sport (or the number and color of medals) is a kind of good that requires resources to be produced and consumed, it is to be expected that a country with a higher income (or GDP per capita), would prefer to win medals in a more diversified range of sports. In terms of RCA, Balassa (1977) pointed out that large countries are expected to have a more diversified export structure (have RCA for more goods but to a smaller degree), mainly because their large domestic markets permit the exploitation of economies of scale in a wide range of industries.

With this in mind it would be useful at this point to preface any further analysis of the topic with some propositions regarding the variance of RCA.

[Proposition 1] *A country has the smallest variance of RCA, $\sigma_R^2 = 0$, when it does not have either a comparative advantage or a comparative disadvantage in any sport.*

[Proposition 2] *For any sport j, if country i has $R_{ij} > (<) 1$, then there exists at least one sport k for which $R_{ik} < (>) 1$.*

Propositions 1 and 2 imply that the lowest bound of the variance of the RCA index is zero and, when a country has RCA (or RCD) in a particular sport, the variance of RCA is greater than zero ($\sigma_R^2 > 0$).

[Proposition 3] *The variance of RCA index for a country (σ_R^2) increases as the country specializes more in those areas where it has RCA and vice versa.*

Propositions 1, 2 and 3 indicate that, as a country diversifies the sources of medals, the RCA of each sport will be closer to one another and, subsequently, the variance of the RCA index will decrease. Therefore, the effects of selected variables on the diversification of medal sources were tested by the following equation

$$\sigma_i = \alpha + \beta_1 POP_i + \beta_2 GDP_i + \beta_3 GPC_i + \beta_4 SCD_i + e_i, \quad (4)$$

where σ is the standard deviation of RCA, POP is population, GPC is GDP per capita, SCD is a dummy variable for former/current socialist countries as defined previously, and the subscript i denotes country i.

Table 5 shows the results of the estimation - how the variance of RCA indexes for countries is related to selected variables. As heteroscedasticity was found, the generalized least squares method (GLS) was used for estimation.[7] The results from estimating equation (4) show that the coefficients for GDP per capita and SCD are significantly negative (or the variance of RCA indexes is higher for a country with higher GDP per capita or a socialist country), which implies that a country wins medals in a more diversified range of sports if its wealth increases or if it is a socialist country. Other economic variables, however, such as GDP and population appear insignificant. No 'scale effect' is found in specialization.[8] The coefficients for GDP per capita and the former/current socialist countries dummy are robust and remain significant when the estimation becomes parsimonious as other insignificant variables are removed, as reported in estimations (4)' and (4)'' in table 5. The consistent and robust coefficient for SCD indicates that these countries win medals in a more diversified range of sports, compared to other countries with the same population, GDP and GDP per capita.

Figures 1, 2, and 3 support the finding, showing the RCA indexes for each sport for selected countries with different levels of income. While countries in the high- income group spread their medal collection over various sports, those in the low -income group concentrate on selected sports only (in this example only one sport for each country). As a result, the RCA indexes for high-income countries show less variance than those for low-income countries. Figure 2 shows that generally, the RCA indexes for middle-income countries look transitional from figure 3 to figure 1. They specialize less than low-income countries, collecting medals from more diversified sports. However, compared to high-income countries, this group of countries diversifies less, but displays higher RCA indexes in the sports in which they collect medals.

5. SUMMARY

This study demonstrates how new features of the Olympic games are disclosed by applying an economic approach based on RCA and specialization. The RCA approach, in line with neoclassical trade models, reveals the relationship between specialization in a certain type of sport and relative factor endowments: including economic, environmental, political and ethnic variables. It is also noted that countries with higher GDP per capita tend to partially specialize, i.e. collect medals from a more diversified range of sports. We have omitted some important features such as the effect of factor mobility[9], or the effect of reward systems in each country. Potentially the most critical omission however, centers on the limited extent to which sport has been disaggregated in this study, and our failure topropose a more detailed recategorization. Some unexpected results obtained in this study might be due to this reason. For example, we *ex ante* expected that a country with a relatively long coastline should have

RCA in swimming; however, this was not supported by the statistics (although it is supported when the ranking of the RCA index is used as shown in Appendix 1). Moreover, table 4 and table A1 show that the results from estimation using RCA indexes and the ranking of RCA indexes are quite different. Future studies should resolve these puzzling situations. As more data are cumulated, we will be able to disaggregate the groups of sports further, which may improve recategorization techniques. An increase in the homogeneity of sports in the same group according to recategorization and disaggregation will contribute to enhancing the reliability of future results.

Also, we used dummy variables (for Asia and Africa) to capture the effects of physiological characteristics, which might be too broad to explain the different attributes of ethnic groups or races. Members of countries belonging to the same continent sometimes possess significantly different physiological characteristics as do members of different races or ethnic groups belonging to the same country. More detailed variables such as weight, height, and the intensity or flexibility of muscles of different nationalities would, if they are available, help to obtain more specific results.

Nevertheless, this study analyzes some previously ignored aspects of one of the world's most important and exciting events, and reports some surprising results, which emerged from interpreting each country's performance. Further exploration, to obtain more data and to reconsider the most appropriate methodology, will produce more valuable findings and contribute to expanding the horizon of economic analysis.

Appendix 1. Ranking of RCA and Determinants

Table A1 reports the results of the estimation of equation A1.

$$N_{ij}^{*} = c_N + \alpha_N'\mathbf{X}_{Ni} + \beta_N'\mathbf{Y}_{Ni} + \gamma_N'\mathbf{D}_i + \varepsilon_{Ni} \qquad \text{(A1)}$$

$$\text{where} \quad N_{ij} = 0 \quad \text{if} \quad N_{ij}^{*} \leq 0$$
$$\text{and} \quad N_{ij} = N_{ij}^{*} \quad \text{if} \quad N_{ij}^{*} > 0.$$

N_{ij} is the ranking of the RCA index (for country i in sport j) observed, $\mathbf{X}_{Ni}$ and $\mathbf{Y}_{Ni}$ are vectors used to rank the relative endowments of economic and natural environment resources for country i, $\mathbf{D}_i$ is a vector of three dummy variables as used in the text, c_N is a constant, α_N, β_N and γ_N are parameter vectors to be estimated, and ε_{Ni} is assumed to be normally distributed with $N(0, \sigma^2)$.

Surprisingly, the results are differ substantially from those obtained from the RCA indexes. In contrast to the RCA index results, swimming is explained by the relative endowment of five variables: coastline (positive), altitude (positive), temperature (negative), population (negative) and SCD (positive). In athletics, all variables except AFD are insignificant. Instead, SCD turns out to be significant and positive. These supplementary relationships are found also in ball games and gymnastics. However, the significance and signs of the three variables – AFD for athletics, temperature for weight games and SCD for gymnastics – are still maintained.

Comparison of the two tables – table 4 and table A1 – provides some noteworthy findings. While the significance of some variables changes across the two tables, only one variable, ASD in weight games, changes its sign. While Asian countries are found to specialize in weight games when RCA indexes are used, they are found to have RCD when rankings are used. As Balance et al. (1987) discussed, to some degree different RCA indexes are destined to be inconsistent. With this in mind, the discrepancy between the findings in the two estimation methods might be more easily understood. As discussed above, only one 'strongly' contradictory result was obtained while others were either consistent or 'weakly' contradictory, in the sense that the direction of effects did not change while significance changed.

Appendix 2. Lists of Countries Analyzed

List of all countries used for analysis

Algeria, Argentina, Australia, the Bahamas, Belarus, Belgium, Brazil, Canada, Chile, China, Colombia, Costa Rica, the Czech Republic, Denmark, Ecuador, Estonia, Ethiopia, Finland, France, Germany, Ghana, Great Britain, Greece, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Kenya, Korea (South), Latvia, Lithuania, Luxembourg, Mexico, Morocco, Namibia, the Netherlands, New Zealand, Nigeria, Norway, Peru, the Philippines, Poland, Portugal, Romania, Russia, Singapore, Slovakia, the Republic of South Africa, Spain, Sweden, Switzerland, Tunisia, Turkey, Uganda, Ukraine, Uruguay, the United States of America and Zambia

List of countries classified as former or current socialist countries

Belarus, China, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russia, Slovakia, Ukraine

List of countries classified as Asian countries

China, Hong Kong, India, Indonesia, Iran, Israel, Japan, Korea (South), the Philippines, Singapore

List of countries classified as African countries

Algeria, Ethiopia, Ghana, Kenya, Morocco, Namibia, Nigeria, the Republic of South Africa, Tunisia, Uganda, Zambia

Endnotes

1. In this regard, the equilibrium of medal production would be analogous to the autarky equilibrium or the equilibrium for non-tradables.

2. Justification for including only 66 countries and classifying Summer Olympic sports into just six groups as shown in table 1 will be provided at the end of this section.

3. Some of natural environmental factors are not usable for selected sports: for example, coastline may not contribute to performance in weight games. Moreover, the specific factor model of trade might be viewed in a similar way. However, as discussed previously, the main concern of this study is not to discuss trade models. In consequence, we do not develop this argument further.

4. The slope of the estimated line or the marginal effect is obtained by

$$\frac{\partial E\left[M_i \mid x_i\right]}{\partial x_i} = \beta\, \Phi(\beta' x_i / \sigma)$$

   where Φ (.) is the standard normal cumulative density function. Therefore, the coefficients reported by tobit are partial changes of coefficients whose observed performance is not zero. We do not report the slopes as we consider the sign and relative size of each coefficient to be sufficient for our discussion. More information on the slopes is available from the authors on request.

5. African countries with the exception of the Republic of South Africa actually did not win any medal in swimming at the three Olympic games investigated in this study. If this country is excluded, we expect the sign of the coefficient for swimming in regards to AFD may be significantly affected. This is consistent with a referee's comment that 'ethnic dummies' sometimes fail to capture performance characteristics of countries' with multi- races.

6. The results of our analysis of total/per capital performance are not discussed in this paper to keep the focus on RCA. These results are available from the authors on request.

7. In this regression, as the dependent variables are zero or positive, a censored regression analysis could be considered. However, as we consider this censoring to be natural and there is no reason to believe that any value of independent variables incurs the dependent variable latent, the results from GLS are reported. Tobit is also used to analyze this regression, and the results are quite similar. The results from tobit are available from the authors on request.

8. It was unexpected that the size of the economy (GDP or population) does not affect diversification significantly. Intuitively, a country's size would impose a certain type of resource restriction, which would retard the diversification of sport performance for a small country. With different settings, Krugman (1980) used Dixit-Stiglitz's model and showed that the number of goods produced is an increasing function of total labor, where this total labor can be regarded as GDP. However, the finding in our study does not confirm the effect of GDP on diversification. It is observed that the winning of medals by some European countries with high per capita incomes but small GDPs is relatively less diversified; however, this observation fails to be generalized for the whole sample. Further investigation is needed.

9. Factor mobility is specifically mentioned here, as its potential effect on Olympic performance would be critical. While medals cannot be traded across countries, certain factors such as athletes can. Further investigation is required to establish whether the performance discrepancy between countries will increase, as countries with larger commercial markets attract more talented athletes (as Krugman-type new trade models predict) or decrease, as factor mobility eventually ensures that the rewards available to athletes remain comparable (as Neoclassical factor mobility models predict).

TABLE 1. RCA INDEX FOR COUNTRIES

	Swimming*	Athletics	Weights	Ball Games	Gymnastics	Other
Algeria	0.0000	2.4011	2.8532	0.0000	0.0000	0.0000
Argentina	0.5565	0.0000	0.7926	7.7908	0.0000	0.0000
Australia	1.7916	0.4392	0.1160	1.4251	0.0000	1.4064
Austria	0.5565	1.0005	0.7926	0.0000	0.0000	2.8832
Bahamas	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Belarus	0.4452	1.6007	1.2681	0.0000	4.1258	0.3844
Belgium	0.9106	0.0000	2.5939	0.0000	0.0000	1.0484
Brazil	1.2521	0.7503	0.7926	3.4085	0.0000	0.2403
Canada	1.8030	0.7203	0.8560	0.2337	0.0000	0.8073
Chile	0.0000	0.0000	0.0000	0.0000	0.0000	5.7664
China	1.0118	0.4093	0.7205	2.9215	1.8754	0.6116
Colombia	0.0000	3.0014	2.3777	0.0000	0.0000	0.0000
Costa Rica	3.3389	0.0000	0.0000	0.0000	0.0000	0.0000
Czech Republic**	1.0274	1.6161	0.1829	2.2473	0.0000	1.1089
Denmark	1.8781	0.0000	0.2972	2.1912	0.0000	1.0812
Ecuador	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Estonia	1.6695	0.0000	0.0000	0.0000	0.0000	2.8832
Ethiopia	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Finland	0.7155	2.1438	1.3587	0.0000	0.0000	0.8238
France	0.8656	0.4446	0.9980	0.2885	0.0000	2.4917
Germany***	1.3286	0.9970	0.7240	0.4448	0.6424	1.1772
Ghana	0.0000	0.0000	0.0000	11.6862	0.0000	0.0000
Great Britain	0.9155	2.1300	0.5369	0.5655	0.0000	1.2091
Greece	0.3035	1.0914	3.0262	0.0000	1.4065	0.0000
Hong Kong	3.3389	0.0000	0.0000	0.0000	0.0000	0.0000
Hungary	1.6695	0.0811	1.0282	0.1579	0.8363	1.1689
India	0.0000	0.0000	0.0000	11.6862	0.0000	0.0000
Indonesia	0.0000	0.0000	0.0000	10.3877	0.0000	0.6407
Iran	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Ireland	2.2259	0.0000	1.5851	0.0000	0.0000	0.0000
Iceland	3.3389	0.0000	0.0000	0.0000	0.0000	0.0000
Israel	1.1130	0.0000	3.1703	0.0000	0.0000	0.0000
Italy	0.9194	0.6960	0.4135	0.3387	0.2242	2.7578
Jamaica	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Japan	0.5683	0.3832	2.7318	0.4973	1.3168	0.3681
Kenya	0.0000	5.5225	0.3804	0.0000	0.0000	0.0000
Korea	0.0000	0.1364	2.2696	3.1871	0.5274	1.1140
Latvia	1.6695	0.0000	0.0000	0.0000	0.0000	2.8832
Lithuania	0.6678	1.2005	0.0000	4.6745	0.0000	1.1533
Luxembourg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mexico	0.8347	3.0014	1.1889	0.0000	0.0000	0.0000
Morocco	0.0000	4.2877	1.3587	0.0000	0.0000	0.0000
Namibia	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000

Continued

	Swimming*	Athletics	Weights	Ball Games	Gymnastics	Other
Netherlands	0.9318	0.1396	0.9953	1.6306	0.0000	2.0115
New Zealand	2.1876	0.2070	0.1640	0.0000	0.0000	1.5907
Nigeria	0.0000	3.6016	1.4266	1.1686	0.0000	0.0000
Norway	1.7573	0.6319	0.5006	1.8452	0.0000	0.6070
Philippines	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Poland	0.7705	0.3463	2.2863	0.2247	0.0000	1.2198
Portugal	1.1130	4.0018	0.0000	0.0000	0.0000	0.0000
Rep. of South Africa	1.4310	2.5726	0.0000	1.6695	0.0000	0.0000
Romania	1.0771	0.3873	0.6903	0.0000	5.9891	0.4650
Russia****	0.5326	1.0496	1.3420	0.4660	2.4204	1.0790
Singapore	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Slovakia	2.2259	0.0000	0.0000	0.0000	0.0000	1.9221
Spain	0.8541	0.9772	0.7741	2.9895	0.7196	0.6705
Sweden	1.2925	0.5809	0.9204	2.2618	0.0000	0.7441
Switzerland	1.1130	0.5002	0.0000	0.9738	1.2893	2.4027
Tunisia	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Turkey	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Uganda	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Ukraine	0.4355	1.0440	1.6541	0.0000	4.7088	0.2507
United States	1.3157	1.5504	0.6771	0.9674	0.6148	0.4774
Uruguay	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zambia	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Zimbabwe	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Notes:

* Also includes water sports

** Czechoslovakia in 1988

*** Includes both East and West Germany in 1988

**** That includes USSR in 1988 and EUN in 1992

TABLE 2 RANKINGS OF SELECTED COUNTRIES IN THE OLYMPICS WITH VARIOUS PERFORMANCE MEASURES

	USA			URS			GER			KOR			CHN			JPN			KEN			ETH		
	TP	**PP**	**RCA**	**TP**	**PP**	**RCA**	**TP**	**PP**	**RCA**	**TP**	**PP**	**RCA**	**TP**	**PP**	**RCA**	**TP**	**PP**	**RCA**	**TP**	**PP**	**RCA**	**TP**	**PP**	**RCA**
SWIM	1	18	16	3	22	38	2	7	15	43	43	43	5	39	24	21	36	35	43	43	43	43	43	43
ATHL	1	14	20	2	10	23	3	7	26	30	38	42	7	43	36	23	40	38	4	5	8	13	27	1
WGHT	3	23	33	1	7	18	2	10	30	4	2	12	7	40	31	5	20	8	31	34	37	43	43	43
BALL	2	13	19	4	15	22	6	11	23	3	5	7	1	23	9	19	26	21	30	30	30	30	30	30
GYM	5	11	12	1	4	4	4	5	11	10	9	13	3	14	5	9	12	7	16	16	16	16	16	16
OTHER	5	27	29	1	14	20	2	5	14	7	17	17	10	32	27	20	30	32	36	36	36	36	36	36
TOTAL	**2**	**27**	**61**	**1**	**16**	**58**	**3**	**8**	**62**	**5**	**17**	**31**	**4**	**52**	**43**	**14**	**39**	**46**	**20**	**32**	**14**	**39**	**51**	**7**

Note: 1. TP = Total Performance; PP = Per Capita Performance; RCA = Revealed Comparative Advantage Index; in TOTAL RCA box the degree of specialisation index (the ranking of standard deviation of the RCA index) is given.
2. USA: The United States of America, URS: Russia, GER: Germany, KOR: South Korea, CHN: People's Republic of China, JPN: Japan, KEN: Kenya, ETH: Ethiopia
3. 66 countries are used in total.

Table 3. DISTRIBUTION OF MEDALS ACROSS SPORTS AND COUNTRIES

	Swimming*	Athletics	Weights	Ball Games	Gymnastics	Other	Total
Algeria	0	6	5	0	0	0	11
Argentina	2	0	1	6	0	0	9
Australia	74	11	3	17	0	39	144
Austria	2	1	3	0	0	5	11
Bahamas	0	3	0	0	0	0	3
Belarus	4	6	7	0	4	2	23
Belgium	7	0	9	0	0	2	18
Brazil	15	4	8	14	0	1	42
Canada	53	13	16	1	0	9	92
Chile	0	0	0	0	0	2	2
China	85	16	32	66	34	30	263
Colombia	0	1	1	0	0	0	2
Costa Rica	5	0	0	0	0	0	5
Czech Republic**	20	16	1	9	0	10	56
Denmark	19	0	1	7	0	6	33
Ecuador	0	3	0	0	0	0	3
Estonia	1	0	0	0	0	3	4
Ethiopia	0	12	0	0	0	0	12
Finland	6	10	6	0	0	3	25
France	33	14	32	3	0	73	155
Germany***	238	88	75	21	20	137	579
Ghana	0	0	0	1	0	0	1
Great Britain	34	37	9	6	0	22	108
Greece	3	5	16	0	3	0	27
Hong Kong	3	0	0	0	0	0	3
Hungary	82	3	31	1	10	27	154
India	0	0	0	1	0	0	1
Indonesia	0	0	0	16	0	2	18
Iran	0	0	12	0	0	0	12
Ireland	10	0	5	0	0	0	15
Island	2	0	0	0	0	0	2
Israel	1	0	3	0	0	0	4
Italy	36	13	13	4	3	71	140
Jamaica	0	22	0	0	0	0	22
Japan	13	5	51	3	4	4	80
Kenya	0	47	4	0	0	0	51
Korea	0	5	82	49	4	41	181
Latvia	2	0	0	0	0	2	4
Lithuania	2	3	0	2	0	1	8
Luxembourg	0	0	0	0	0	0	0
Mexico	1	3	1	0	0	0	5
Morocco	0	9	2	0	0	0	11
Namibia	0	8	0	0	0	0	8
Netherlands	19	3	10	11	0	29	72

Continued

New Zealand	35	1	1	0	0	14	51
Nigeria	0	10	5	3	0	0	18
Norway	20	4	6	5	0	5	40
Philippines	0	0	4	0	0	0	4
Poland	17	6	46	2	0	21	92
Portugal	1	6	0	0	0	0	7
Rep. of South Africa	7	7	0	2	0	0	16
Romania	40	9	13	0	43	10	115
Russia****	104	120	195	27	114	125	685
Singapore	0	0	0	0	0	0	0
Slovakia	5	0	0	0	0	1	6
Spain	29	15	13	21	5	12	95
Sweden	22	6	8	10	0	6	52
Switzerland	10	1	0	3	3	10	27
Tunisia	0	0	1	0	0	0	1
Turkey	0	0	32	0	0	0	32
Uganda	0	1	0	0	0	0	1
Ukraine	6	6	14	0	16	1	43
United States	252	174	83	57	21	45	632
Uruguay	0	0	0	0	0	0	0
Zambia	0	2	0	0	0	0	2
Zimbabwe	0	0	0	0	0	0	0
TOTAL	1320	735	860	368	284	771	4338
	(30.43%)	(16.94%)	(19.82%)	(8.48%)	(6.55%)	(17.77%)	(100%)

Notes:

Medals are for three Summer Olympics from 1988 to 1996.

* Also includes water sports

** Czechoslovakia in 1988

*** Include both East and West Germany in 1988

**** That includes USSR in 1988 and EUN in 1992

TABLE 4 REVEALED COMPARATIVE ADVANTAGE OF EACH COUNTRY IN THE OLYMPICS

	SWIM	ATHL	WGHT	BALL	GYM	OTHER
RLND	**-0.0474**	**0.0606*** **	**-0.0068**	**0.2049**	**0.2518**	**0.018**
	(0.2086)	(0.0194)	(0.0183)	(0.1869)	(0.8048)	(0.0282)
RCST	**0.0368**	**-0.0394*** **	**0.0102**	**-0.0614**	**0.0001**	**-0.0482** **
	(0.0625)	(0.0121)	(0.0175)	(0.0663)	(0.0467)	(0.0229)
RALT	**0.1091**	**0.8279*** **	**-0.9662** **	**-0.2696**	**-0.2716**	**-0.0686**
	(0.3956)	(0.2157)	(0.3756)	(0.6007)	(0.1286)	(0.4827)
RTMP	**0.201**	**0.2794***	**0.5993*** **	**0.2218**	**-0.2225**	**0.2413**
	(0.2665)	(0.1541)	(0.1223)	(0.3238)	(0.2664)	(0.1638)
RPOP	**0.0816**	**-0.0325**	**-0.0374**	**0.255** **	**-0.0032**	**0.1006** **
	(0.084)	(0.0375)	(0.0344)	(0.1132)	(0.0603)	(0.0438)
RGDP	**0.0072**	**0.0142**	**0.0754*** **	**-0.0817**	**0.2981**	**-0.1211*** **
	(0.071)	(0.0139)	(0.0202)	(0.0757)	(0.5696)	(0.0263)
RGPC	**0.4706**	**0.2651** **	**-0.4549** **	**0.1444**	**0.1014**	**1.0465*** **
	(0.3842)	(0.1184)	(0.1899)	(0.5681)	(0.1823)	(0.2043)
SCD	**0.9325**	**0.2403**	**-0.8199** **	**-3.1427**	**1.7791*** **	**0.6533** **
	(0.821)	(0.2054)	(0.3528)	(2.1967)	(0.4639)	(0.2993)
ASD	**-0.9998***	**-0.0205**	**1.8675*** **	**0.4679**	**0.0640**	**-1.2775*** **
	(0.5835)	(0.2552)	(0.2029)	(1.0281)	(0.4249)	(0.3284)
AFD	**-8.8325**	**1.909*** **	**2.0404** **	**-0.4683**	**-0.0088**	**-21.7727**
	(32.4327)	(0.2613)	(0.6286)	(2.0873)	(0.4202)	(61.0483)
σ	1.6734	10.8795	9.3037	20.5843	4.1845	7.4691
Log-L	-5.9527	-9.6491	-25.2566	-39.4279	-88.0643	-5.3829
n	66	66	66	66	66	66

Note: 1. Numbers in parentheses are standard deviations. ***, **, * denote that the coefficient is significant at the 1, 5, and 10% level respectively.
2. RLND: relative landmass, RCST: relative coast length, RALT: relative altitude, RTMP: relative temperature, RPOP: relative population, RGDP: relative Gross Domestic Product, RGPC: relative GDP per capita, SCD: former/current socialist countries dummy, ASD: Asian countries dummy, AFD: African countries dummy

TABLE A1 RANKING OF REVEALED COMPARATIVE ADVANTAGE OF EACH COUNTRY IN THE OLYMPICS

	SWIM	ATHL	WGHT	BALL	GYM	OTHER
NLND	**-0.7909**	**-0.7576***	**0.3192**	**1.4692*****	**-0.236**	**0.0937**
	(0.1504)	(0.4035)	(0.3637)	(0.5026)	(0.2912)	(0.2198)
NCST	**0.7533*****	**0.2694**	**-0.4617***	**-1.0411****	**0.0635**	**-0.0937**
	(0.1463)	(0.2943)	(0.2684)	(0.515)	(0.2184)	(0.1262)
NALT	**0.8466*****	**0.426***	**-0.0909**	**-1.268*****	**-0.0073**	**-0.5044****
	(0.1308)	(0.2516)	(0.1937)	(0.3926)	(0.2187)	(0.2146)
NTMP	**-0.2192*****	**0.063**	**0.2079****	**0.2283**	**-0.2727***	**-0.4562*****
	(0.0790)	(0.2128)	(0.0838)	(0.2513)	(0.1687)	(0.1478)
NPOP	**-0.9558****	**0.6388**	**-0.2547**	**-0.9263***	**0.9147****	**0.7278****
	(0.4611)	(0.5410)	(0.3426)	(0.5329)	(0.393)	(0.3687)
NGDP	**0.0559**	**0.5929**	**0.5691**	**4.0002*****	**-0.3605**	**-0.7612**
	(0.57)	(0.773)	(0.587)	(0.8786)	(0.464)	(0.5177)
NGPC	**0.8451**	**0.2942**	**-0.31**	**-1.249****	**0.7574****	**1.4724*****
	(0.5206)	(0.6754)	(0.4213)	(0.5187)	(0.3808)	(0.477)
SCD	**32.1095*****	**22.6575*****	**3.4665**	**-17.1656**	**36.9382*****	**29.2955*****
	(6.3688)	(8.6651)	(6.9113)	(47.1154)	(9.2996)	(9.4427)
ASD	**2.2488**	**-21.0564**	**-52.4367*****	**-1.5285**	**3.4496**	**8.5826**
	(9.4897)	(14.7427)	(14.7553)	(15.7393)	(8.856)	(17.4481)
AFD	**-33.9755**	**46.4329*****	**3.073**	**50.8552*****	**3.2944**	**-39.6675**
	(185.176)	(11.1496)	(19.7739)	(18.4944)	(10.7088)	(0.37E+10)
σ	133.3171	302.8986	118.1682	306.9548	25.4355	206.5712
Log-L	-172.7484	-201.675	-190.344	-130.7946	-287.6384	-145.9266
n	66	66	66	66	66	66

Note: 1. Numbers in parentheses are standard deviations. ***, **, * denote that the coefficient is significant at the 1, 5, and 10% level respectively.
2. NLND: ranking of landmass, NCST: ranking of the length of coast, NALT: ranking of altitude, NTMP: ranking of temperature, NPOP: ranking of population, NGDP: ranking of Gross Domestic Product, NGPC: ranking of GDP per capita, SCD: former/current socialist countries dummy, ASD: Asian countries dummy, AFD: African countries dummy

TABLE 5 DIVERSIFICATION IN REVEALED COMPARATIVE ADVANTAGE

	(4)	(4)'	(4)''
GDP	**-0.0412** (0.0431)	-----	-----
POP	**0.0599** (0.1674)	**0.0490** (0.1635)	-----
GPC	**-0.5322***** (0.1016)	**-0.5821***** (0.1045)	**-0.5971***** (0.0900)
SCD	**-0.9847***** (0.3568)	**-0.9804***** (0.3635)	**-0.9430***** (0.2058)
Adj R^2	0.4153	0.4136	0.4012
n	62	62	62

Note: Numbers in parentheses are standard deviations. *** denotes that the coefficient is significant at the 1% level.

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TABLE 1. RCA INDEX FOR COUNTRIES

	Swimming*	Athletics	Weights	Ball Games	Gymnastics	Other
Algeria	0.0000	2.4011	2.8532	0.0000	0.0000	0.0000
Argentina	0.5565	0.0000	0.7926	7.7908	0.0000	0.0000
Australia	1.7916	0.4392	0.1160	1.4251	0.0000	1.4064
Austria	0.5565	1.0005	0.7926	0.0000	0.0000	2.8832
Bahamas	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Belarus	0.4452	1.6007	1.2681	0.0000	4.1258	0.3844
Belgium	0.9106	0.0000	2.5939	0.0000	0.0000	1.0484
Brazil	1.2521	0.7503	0.7926	3.4085	0.0000	0.2403
Canada	1.8030	0.7203	0.8560	0.2337	0.0000	0.8073
Chile	0.0000	0.0000	0.0000	0.0000	0.0000	5.7664
China	1.0118	0.4093	0.7205	2.9215	1.8754	0.6116
Colombia	0.0000	3.0014	2.3777	0.0000	0.0000	0.0000
Costa Rica	3.3389	0.0000	0.0000	0.0000	0.0000	0.0000
Czech Republic**	1.0274	1.6161	0.1829	2.2473	0.0000	1.1089
Denmark	1.8781	0.0000	0.2972	2.1912	0.0000	1.0812
Ecuador	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Estonia	1.6695	0.0000	0.0000	0.0000	0.0000	2.8832
Ethiopia	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Finland	0.7155	2.1438	1.3587	0.0000	0.0000	0.8238
France	0.8656	0.4446	0.9980	0.2885	0.0000	2.4917
Germany***	1.3286	0.9970	0.7240	0.4448	0.6424	1.1772
Ghana	0.0000	0.0000	0.0000	11.6862	0.0000	0.0000
Great Britain	0.9155	2.1300	0.5369	0.5655	0.0000	1.2091
Greece	0.3035	1.0914	3.0262	0.0000	1.4065	0.0000
Hong Kong	3.3389	0.0000	0.0000	0.0000	0.0000	0.0000
Hungary	1.6695	0.0811	1.0282	0.1579	0.8363	1.1689
India	0.0000	0.0000	0.0000	11.6862	0.0000	0.0000
Indonesia	0.0000	0.0000	0.0000	10.3877	0.0000	0.6407
Iran	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Ireland	2.2259	0.0000	1.5851	0.0000	0.0000	0.0000
Iceland	3.3389	0.0000	0.0000	0.0000	0.0000	0.0000
Israel	1.1130	0.0000	3.1703	0.0000	0.0000	0.0000
Italy	0.9194	0.6960	0.4135	0.3387	0.2242	2.7578
Jamaica	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Japan	0.5683	0.3832	2.7318	0.4973	1.3168	0.3681
Kenya	0.0000	5.5225	0.3804	0.0000	0.0000	0.0000
Korea	0.0000	0.1364	2.2696	3.1871	0.5274	1.1140
Latvia	1.6695	0.0000	0.0000	0.0000	0.0000	2.8832
Lithuania	0.6678	1.2005	0.0000	4.6745	0.0000	1.1533
Luxembourg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mexico	0.8347	3.0014	1.1889	0.0000	0.0000	0.0000
Morocco	0.0000	4.2877	1.3587	0.0000	0.0000	0.0000
Namibia	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Netherlands	0.9318	0.1396	0.9953	1.6306	0.0000	2.0115
New Zealand	2.1876	0.2070	0.1640	0.0000	0.0000	1.5907
Nigeria	0.0000	3.6016	1.4266	1.1686	0.0000	0.0000
Norway	1.7573	0.6319	0.5006	1.8452	0.0000	0.6070
Philippines	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Poland	0.7705	0.3463	2.2863	0.2247	0.0000	1.2198
Portugal	1.1130	4.0018	0.0000	0.0000	0.0000	0.0000

(to be continued)

TABLE 1 RCA INDEX FOR COUNTRIES

(CONTINUED)

	Swimming	Athletics	Weights	Ball Games	Gymnastics	Other
Rep. of South Africa	1.4310	2.5726	0.0000	1.6695	0.0000	0.0000
Romania	1.0771	0.3873	0.6903	0.0000	5.9891	0.4650
Russia****	0.5326	1.0496	1.3420	0.4660	2.4204	1.0790
Singapore	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Slovakia	2.2259	0.0000	0.0000	0.0000	0.0000	1.9221
Spain	0.8541	0.9772	0.7741	2.9895	0.7196	0.6705
Sweden	1.2925	0.5809	0.9204	2.2618	0.0000	0.7441
Switzerland	1.1130	0.5002	0.0000	0.9738	1.2893	2.4027
Tunisia	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Turkey	0.0000	0.0000	4.7554	0.0000	0.0000	0.0000
Uganda	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Ukraine	0.4355	1.0440	1.6541	0.0000	4.7088	0.2507
United States	1.3157	1.5504	0.6771	0.9674	0.6148	0.4774
Uruguay	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zambia	0.0000	6.0027	0.0000	0.0000	0.0000	0.0000
Zimbabwe	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Notes:

* Also includes water sports

** Czechoslovakia in 1988

*** Includes both East and West Germany in 1988

**** That includes USSR in 1988 and EUN in 1992

TABLE 2 RANKINGS OF SELECTED COUNTRIES IN THE OLYMPICS WITH VARIOUS PERFORMANCE MEASURES

	USA			URS			GER			KOR			CHN			JPN			KEN			ETH		
	TP	PP	RC	TP	PP	RC	TP	PP	RC	TP	PP	RC	TP	PP	RC	TP	PP	RC	TP	PP	RC	TP	PP	RC
SWIM	1	18	16	3	22	38	2	7	15	43	43	43	5	39	24	21	36	35	43	43	43	43	43	43
ATHL	1	14	20	2	10	23	3	7	26	30	38	42	7	43	36	23	40	38	4	5	8	13	27	1
WGHT	3	23	33	1	7	18	2	10	30	4	2	12	7	40	31	5	20	8	31	34	37	43	43	43
BALL	2	13	19	4	15	22	6	11	23	3	5	7	1	23	9	19	26	21	30	30	30	30	30	30
GYM	5	11	12	1	4	4	4	5	11	10	9	13	3	14	5	9	12	7	16	16	16	16	16	16
OTHER	5	27	29	1	14	20	2	5	14	7	17	17	10	32	27	20	30	32	36	36	36	36	36	36
TOTAL	**2**	**27**	**61**	**1**	**16**	**58**	**3**	**8**	**62**	**5**	**17**	**31**	**4**	**52**	**43**	**14**	**39**	**46**	**20**	**32**	**14**	**39**	**51**	**7**

Note: 1. TP = Total Performance; PP = Per Capita Performance; RCA = Revealed Comparative Advantage Index; in TOTAL RCA box the degree of specialisation index (the ranking of standard deviation of the RCA index) is given.
2. USA: The United States of America, URS: Russia, GER: Germany, KOR: South Korea, CHN: People's Republic of China, JPN: Japan, KEN: Kenya, ETH: Ethiopia
3. 66 countries are used in total.

Table 3. DISTRIBUTION OF MEDALS ACROSS SPORTS AND COUNTRIES

	Swimming*	Athletics	Weights	Ball Games	Gymnastics	Other	Total
Algeria	0	6	5	0	0	0	11
Argentina	2	0	1	6	0	0	9
Australia	74	11	3	17	0	39	144
Austria	2	1	3	0	0	5	11
Bahamas	0	3	0	0	0	0	3
Belarus	4	6	7	0	4	2	23
Belgium	7	0	9	0	0	2	18
Brazil	15	4	8	14	0	1	42
Canada	53	13	16	1	0	9	92
Chile	0	0	0	0	0	2	2
China	85	16	32	66	34	30	263
Colombia	0	1	1	0	0	0	2
Costa Rica	5	0	0	0	0	0	5
Czech Republic**	20	16	1	9	0	10	56
Denmark	19	0	1	7	0	6	33
Ecuador	0	3	0	0	0	0	3
Estonia	1	0	0	0	0	3	4
Ethiopia	0	12	0	0	0	0	12
Finland	6	10	6	0	0	3	25
France	33	14	32	3	0	73	155
Germany***	238	88	75	21	20	137	579
Ghana	0	0	0	1	0	0	1
Great Britain	34	37	9	6	0	22	108
Greece	3	5	16	0	3	0	27
Hong Kong	3	0	0	0	0	0	3
Hungary	82	3	31	1	10	27	154
India	0	0	0	1	0	0	1
Indonesia	0	0	0	16	0	2	18
Iran	0	0	12	0	0	0	12
Ireland	10	0	5	0	0	0	15
Island	2	0	0	0	0	0	2
Israel	1	0	3	0	0	0	4
Italy	36	13	13	4	3	71	140
Jamaica	0	22	0	0	0	0	22
Japan	13	5	51	3	4	4	80
Kenya	0	47	4	0	0	0	51
Korea	0	5	82	49	4	41	181
Latvia	2	0	0	0	0	2	4
Lithuania	2	3	0	2	0	1	8
Luxembourg	0	0	0	0	0	0	0
Mexico	1	3	1	0	0	0	5
Morocco	0	9	2	0	0	0	11
Namibia	0	8	0	0	0	0	8
Netherlands	19	3	10	11	0	29	72
New Zealand	35	1	1	0	0	14	51
Nigeria	0	10	5	3	0	0	18
Norway	20	4	6	5	0	5	40
Philippines	0	0	4	0	0	0	4
Poland	17	6	46	2	0	21	92
Portugal	1	6	0	0	0	0	7

(to be continued)

Table 3 DISTRIBUTION OF MEDALS ACROSS SPORTS AND COUNTRIES (CONTINUED)

	Swimming	Athletics	Weights	Ball Games	Gymnastics	Other	TOTAL
Rep. of South Africa	7	7	0	2	0	0	16
Romania	40	9	13	0	43	10	115
Russia****	104	120	195	27	114	125	685
Singapore	0	0	0	0	0	0	0
Slovakia	5	0	0	0	0	1	6
Spain	29	15	13	21	5	12	95
Sweden	22	6	8	10	0	6	52
Switzerland	10	1	0	3	3	10	27
Tunisia	0	0	1	0	0	0	1
Turkey	0	0	32	0	0	0	32
Uganda	0	1	0	0	0	0	1
Ukraine	6	6	14	0	16	1	43
United States	252	174	83	57	21	45	632
Uruguay	0	0	0	0	0	0	0
Zambia	0	2	0	0	0	0	2
Zimbabwe	0	0	0	0	0	0	0
TOTAL	1320	735	860	368	284	771	4338
	(30.43%)	(16.94%)	(19.82%)	(8.48%)	(6.55%)	(17.77%)	(100%)

Notes:
Medals are for three Summer Olympics from 1988 to 1996.
* Also includes water sports
** Czechoslovakia in 1988
*** Include both East and West Germany in 1988
**** That includes USSR in 1988 and EUN in 1992

TABLE 4 REVEALED COMPARATIVE ADVANTAGE OF EACH COUNTRY IN THE OLYMPICS

	SWIM	ATHL	WGHT	BALL	GYM	OTHER
RLND	**-0.0474**	**0.0606*** **	**-0.0068**	**0.2049**	**0.2518**	**0.018**
	(0.2086)	(0.0194)	(0.0183)	(0.1869)	(0.8048)	(0.0282)
RCST	**0.0368**	**-0.0394*** **	**0.0102**	**-0.0614**	**0.0001**	**-0.0482** **
	(0.0625)	(0.0121)	(0.0175)	(0.0663)	(0.0467)	(0.0229)
RALT	**0.1091**	**0.8279*** **	**-0.9662** **	**-0.2696**	**-0.2716**	**-0.0686**
	(0.3956)	(0.2157)	(0.3756)	(0.6007)	(0.1286)	(0.4827)
RTMP	**0.201**	**0.2794***	**0.5993*** **	**0.2218**	**-0.2225**	**0.2413**
	(0.2665)	(0.1541)	(0.1223)	(0.3238)	(0.2664)	(0.1638)
RPOP	**0.0816**	**-0.0325**	**-0.0374**	**0.255** **	**-0.0032**	**0.1006** **
	(0.084)	(0.0375)	(0.0344)	(0.1132)	(0.0603)	(0.0438)
RGDP	**0.0072**	**0.0142**	**0.0754*** **	**-0.0817**	**0.2981**	**-0.1211*** **
	(0.071)	(0.0139)	(0.0202)	(0.0757)	(0.5696)	(0.0263)
RGPC	**0.4706**	**0.2651** **	**-0.4549** **	**0.1444**	**0.1014**	**1.0465*** **
	(0.3842)	(0.1184)	(0.1899)	(0.5681)	(0.1823)	(0.2043)
SCD	**0.9325**	**0.2403**	**-0.8199** **	**-3.1427**	**1.7791*** **	**0.6533** **
	(0.821)	(0.2054)	(0.3528)	(2.1967)	(0.4639)	(0.2993)
ASD	**-0.9998***	**-0.0205**	**1.8675*** **	**0.4679**	**0.0640**	**-1.2775*** **
	(0.5835)	(0.2552)	(0.2029)	(1.0281)	(0.4249)	(0.3284)
AFD	**-8.8325**	**1.909*** **	**2.0404** **	**-0.4683**	**-0.0088**	**-21.7727**
	(32.4327)	(0.2613)	(0.6286)	(2.0873)	(0.4202)	(61.0483)
σ	1.6734	10.8795	9.3037	20.5843	4.1845	7.4691
Log-L	-5.9527	-9.6491	-25.2566	-39.4279	-88.0643	-5.3829
n	66	66	66	66	66	66

Note: 1. Numbers in parentheses are standard deviations. ***, **, * denote that the coefficient is significant at the 1, 5, and 10% level respectively.

2. RLND: relative landmass, RCST: relative coast length, RALT: relative altitude, RTMP: relative temperature, RPOP: relative population, RGDP: relative Gross Domestic Product, RGPC: relative GDP per capita, SCD: former/current socialist countries dummy, ASD: Asian countries dummy, AFD: African countries dummy

TABLE A1 RANKING OF REVEALED COMPARATIVE ADVANTAGE OF EACH COUNTRY IN THE OLYMPICS

	SWIM	ATHL	WGHT	BALL	GYM	OTHER
NLND	**-0.7909**	**-0.7576***	**0.3192**	**1.4692*****	**-0.236**	**0.0937**
	(0.1504)	(0.4035)	(0.3637)	(0.5026)	(0.2912)	(0.2198)
NCST	**0.7533*****	**0.2694**	**-0.4617***	**-1.0411****	**0.0635**	**-0.0937**
	(0.1463)	(0.2943)	(0.2684)	(0.515)	(0.2184)	(0.1262)
NALT	**0.8466*****	**0.426***	**-0.0909**	**-1.268*****	**-0.0073**	**-0.5044****
	(0.1308)	(0.2516)	(0.1937)	(0.3926)	(0.2187)	(0.2146)
NTMP	**-0.2192*****	**0.063**	**0.2079****	**0.2283**	**-0.2727***	**-0.4562*****
	(0.0790)	(0.2128)	(0.0838)	(0.2513)	(0.1687)	(0.1478)
NPOP	**-0.9558****	**0.6388**	**-0.2547**	**-0.9263***	**0.9147****	**0.7278****
	(0.4611)	(0.5410)	(0.3426)	(0.5329)	(0.393)	(0.3687)
NGDP	**0.0559**	**0.5929**	**0.5691**	**4.0002*****	**-0.3605**	**-0.7612**
	(0.57)	(0.773)	(0.587)	(0.8786)	(0.464)	(0.5177)
NGPC	**0.8451**	**0.2942**	**-0.31**	**-1.249****	**0.7574****	**1.4724*****
	(0.5206)	(0.6754)	(0.4213)	(0.5187)	(0.3808)	(0.477)
SCD	**32.1095*****	**22.6575*****	**3.4665**	**-17.1656**	**36.9382*****	**29.2955*****
	(6.3688)	(8.6651)	(6.9113)	(47.1154)	(9.2996)	(9.4427)
ASD	**2.2488**	**-21.0564**	**-52.4367*****	**-1.5285**	**3.4496**	**8.5826**
	(9.4897)	(14.7427)	(14.7553)	(15.7393)	(8.856)	(17.4481)
AFD	**-33.9755**	**46.4329*****	**3.073**	**50.8552*****	**3.2944**	**-39.6675**
	(185.176)	(11.1496)	(19.7739)	(18.4944)	(10.7088)	(0.37E+10)
σ	133.3171	302.8986	118.1682	306.9548	25.4355	206.5712
Log-L	-172.7484	-201.675	-190.344	-130.7946	-287.6384	-145.9266
n	66	66	66	66	66	66

Note: 1. Numbers in parentheses are standard deviations. ***, **, * denote that the coefficient is significant at the 1, 5, and 10% level respectively.
2. NLND: ranking of landmass, NCST: ranking of the length of coast, NALT: ranking of altitude, NTMP: ranking of temperature, NPOP: ranking of population, NGDP: ranking of Gross Domestic Product, NGPC: ranking of GDP per capita, SCD: former/current socialist countries dummy, ASD: Asian countries dummy, AFD: African countries dummy

TABLE 5 DIVERSIFICATION IN REVEALED COMPARATIVE ADVANTAGE

	(4)	(4)'	(4)''
GDP	**-0.0412** (0.0431)	-----	------
POP	**0.0599** (0.1674)	**0.0490** (0.1635)	------
GPC	**-0.5322***** (0.1016)	**-0.5821***** (0.1045)	**-0.5971***** (0.0900)
SCD	**-0.9847***** (0.3568)	**-0.9804***** (0.3635)	**-0.9430***** (0.2058)
Adj R^2	0.4153	0.4136	0.4012
n	66	66	66

Note: Numbers in parentheses are standard deviations. *** denotes that the coefficient is significant at the 1% level.

FIGURE 1

REVEALED COMPARATIVE ADVANTAGE FOR

HIGH-INCOME COUNTRIES

NOTE: GER: Germany, USA: the United States of America, SUI: Switzerland, JPN: Japan

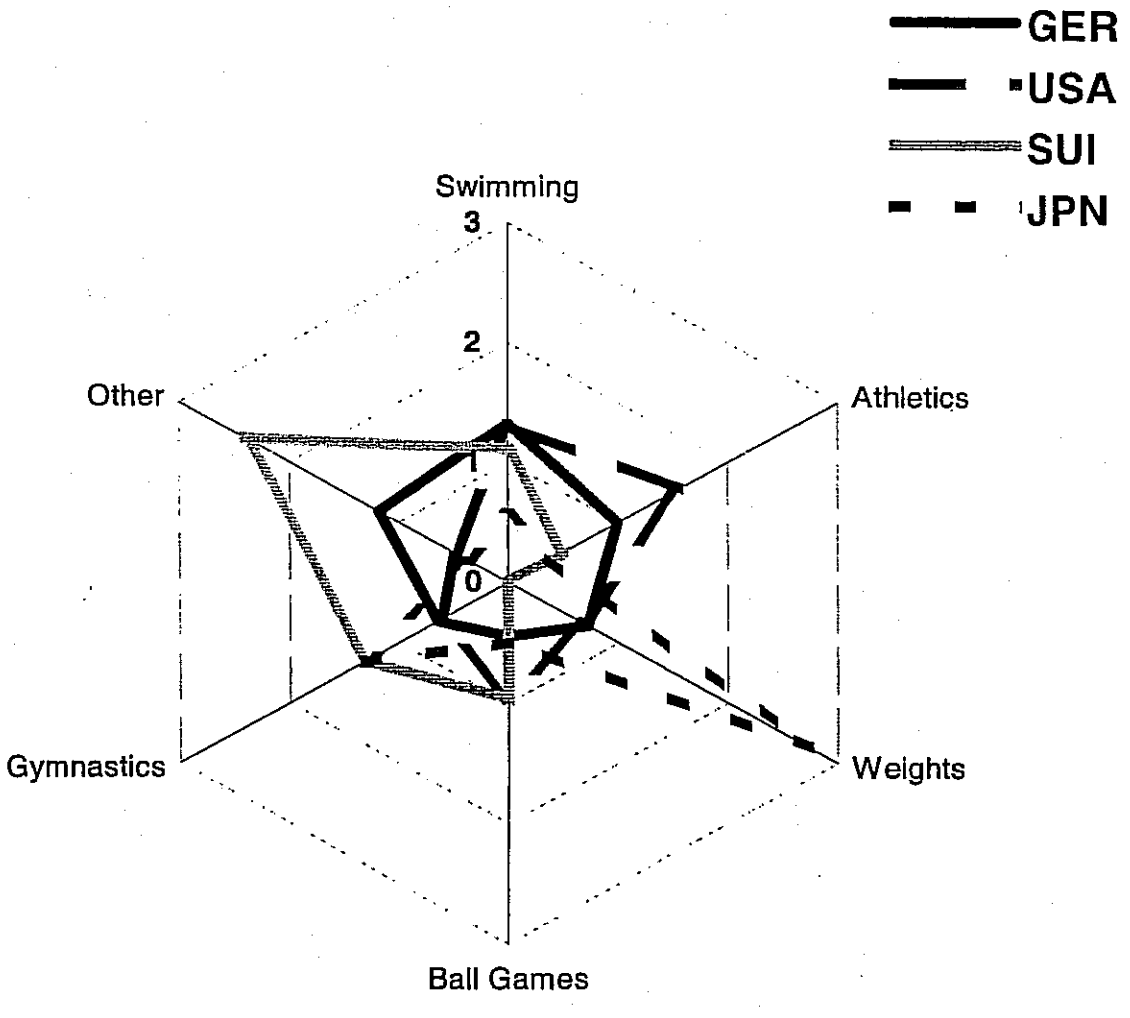


FIGURE 2

REVEALED COMPARATIVE ADVANTAGE FOR

MIDDLE-INCOME COUNTRIES

NOTE: RSA: Republic of South Africa, MEX: Mexico, GRE: Greece, KOR: South Korea

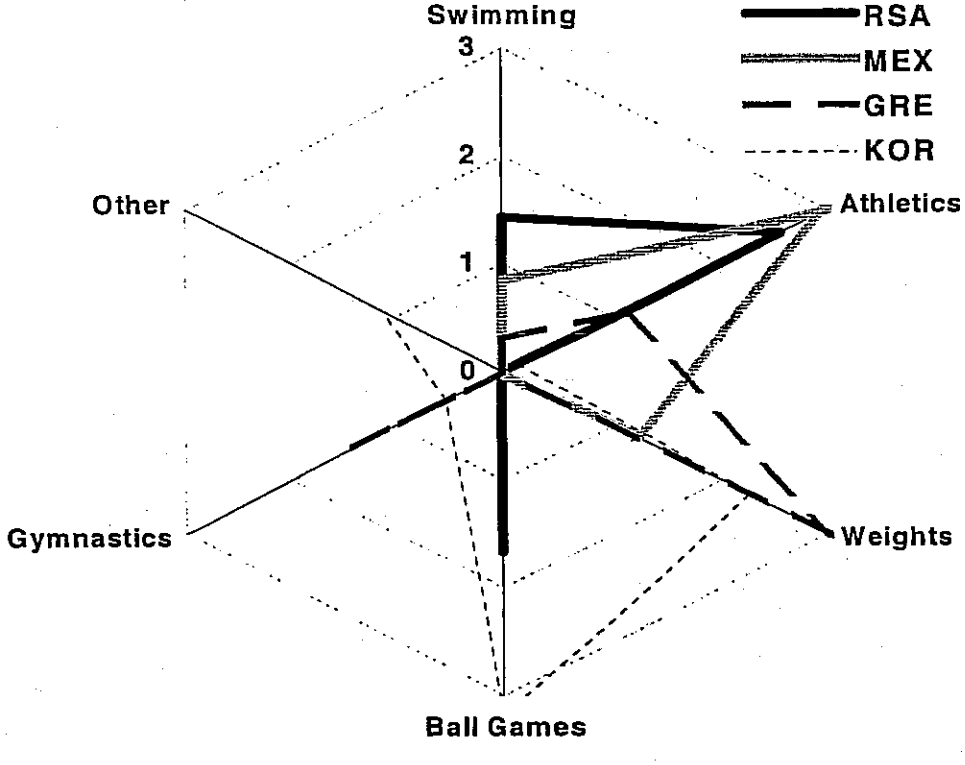
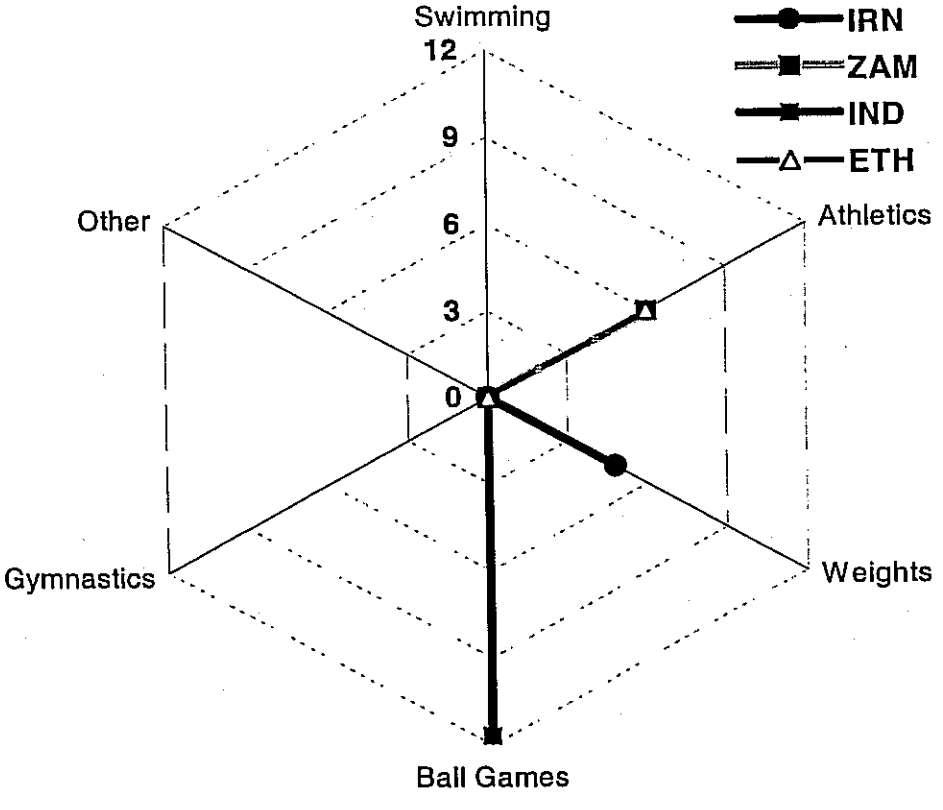


FIGURE 3

REVEALED COMPARATIVE ADVANTAGE FOR LOW-INCOME COUNTRIES

NOTE: IRN: Iran, ZAM: Zambia, IND: India, ETH: Ethiopia



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