

**NATIONAL SYSTEM OF INNOVATION AND TECHNOLOGICAL DIFFERENTIATION:
A MULTI-COUNTRY EVOLUTIONARY MODEL**
(Preliminary Version)

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Abstract:

The paper introduces an agent-based model in which the national system of innovation (NSI) is a main determinant of the wealth of nations. The model is defined as a self-organizing economy where agents are countries with their own capabilities for imitation and innovation. The interactions among countries are given by the relative competitiveness of a country in world economy, which is represented by functions that connect their prices, demands, technologies, and incomes. The simulations show that the model reproduces countries hierarchies that have been found in several empirical studies.

Key words: national system of innovation, technological change, innovation, growth

JEL: O33, O41, F43, C68

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1. INTRODUCTION

Recently, by using statistics of patents (USPTO) and scientific papers (ISI), we have studied the interplay between science and technology and its influences on the level of development (country GNP per capita). We have identified strong relations among these three variables and threshold levels in the scientific production, beyond which the use of scientific output by the technological sector increases (Bernardes & Albuquerque, 2003).

In this work, we present a simple model that aims to reproduce those correlations and the hierarchy of countries of our empirical studies. We created an artificial world economy populated by agents (countries) where the interactions among countries are represented by functions that connect their prices, demands, technologies, and incomes.¹

Starting from random values for the country technology and income, the artificial world economy self-organizes itself and creates hierarchies of countries that are similar to the ones found in our empirical studies. Technology is measured, and we show that it is proportional to the country's production of patents and scientific articles, which are conventional proxies of the national systems of innovation efficiency.

2. COUNTRY ECONOMIC STRUCTURE (INTERNAL RULES)

2.1. PRICE AND PRODUCTION

The equations that define the level of production and price are:

$$Q_i = (T_i \cdot L_i) + V_i \quad (1)$$

$$P_i = (Y_i / Q_i) \quad (2)$$

$$P_i = Y_i / [(T_i \cdot L_i) + V_i]$$

Where Q_i is the amount of goods produced by country i , T_i represents country technology, L_i stands for population or labor force, and V_i is the unsold good of previous period. The country income (US\$ GDP) is Y_i and P_i is the price of one unit of good Q_i . Population (or labor force) is constant; thus Q_i depends mostly on T_i , which is the output of the national system of innovation. The price level is set by an adaptive rule: everything else constant, unsold stock and decreasing national income reduce prices and increase competitiveness, while falling inventory and raising income do the opposite.

2.2. COMPETITIVENESS

The country competitiveness C_i has an inverse relation with its price:

$$C_i = (1 / P_i) \quad (3)$$

¹ See Aversi et al. (1994), Silverberg et al. (1988) and Winter et al. (2000) on similar modeling and simulations.

The global competitiveness C_g is defined by the country competitiveness C_i weighted by its market share M_i (the share of the country in the world economy measured by its income):

$$\begin{aligned} M_i &= Y_i / \sum Y_i \\ C_g &= \sum(M_i \cdot C_i) \end{aligned} \quad (4)$$

2.3. TECHNOLOGICAL CHANGE

Countries change their technology in order to increase its competitiveness and wealth. To do so, it must change its technology, which depends on the previous level of its own knowledge (T_i), on the technological information spilled from international sources (T_g). Country capabilities to create new technologies are represented by patents and articles per capita (PAT_i and ART_i):

$$T_{i2} = T_{i1} + N_i \quad (5)$$

$$N_i = (T_g \cdot PT_i \cdot AT_i)^{1/3}, \text{ where } 0 < N_i \quad (6)$$

$$T_g = \sum(M_i \cdot T_i) \quad (7)$$

The coefficient N_i is a proxy to the national system of innovation, which corresponds to the country's innovation capabilities plus the spillovers of technologies of the global economy (T_g). Therefore, the national system of innovation N_i summarizes the country capabilities to imitate and innovate when other countries increase their competitiveness by technological changes.

2.4. INCOME

The country income is Y_i plus the income not spent in the previous period S_i (savings). The wage or per capita income is the country income distributed among its population.

$$Y_i = K_i + S_i \quad (8)$$

$$W_i = Y_i / L_i \quad (9)$$

The global income is the sum of all country incomes:

$$Y_g = \sum Y_i \quad (10)$$

3. COUNTRY DEMAND, CAPITAL AND SAVINGS

3.1. MARKET SHARE AND DEMAND

A replicator dynamics equation models the changes of the country's market share (equation 11). The replicator dynamics is routinely used in evolutionary game theory, versions of cobweb models and other dynamic sets. It is used to represent sluggish changes; in this case

the σ is the speed of the market share changes due to asymmetries in the country and the global competitiveness.

$$M_{i2} = M_{i1} \cdot [1 + \sigma \cdot \{(C_i / C_g) - 1\}], \text{ where } 0 < \sigma < 1, \text{ and } \sum M_i = 1 \quad (11)$$

The country's demand D_{Yi} (units of money) is a share M_i of the global income:

$$D_{Yi} = M_i \cdot Y_g$$

The country's demand D_i (unit of goods) is given by:

$$D_i = D_{Yi} / P_i = (M_i \cdot Y_g) / P_i \quad (12)$$

3.2. CAPITAL, INVENTORY AND SAVINGS

There is recurrent disequilibrium on the amount of goods demanded and supplied. Thus, three simple rules were created:

$$\begin{aligned} \text{When } D_i = Q_i, \text{ then: } & K_i = P_i \cdot Q_i & (13) \\ & S_g = S_g + S_i = S_g + 0 \\ & V_g = V_g + V_i = V_g + 0 \end{aligned}$$

$$\begin{aligned} \text{When } D_i > Q_i, \text{ then: } & K_i = P_i \cdot Q_i & (14) \\ & S_g = S_g + S_i = S_g + [P_i \cdot (D_i - Q_i)] \\ & V_g = V_g + V_i = V_g + 0 \end{aligned}$$

$$\begin{aligned} \text{When } D_i < Q_i, \text{ then: } & K_i = P_i \cdot D_i & (15) \\ & S_g = S_g + S_i = S_g + 0 \\ & V_g = V_g + V_i = V_g + (Q_i - D_i) \end{aligned}$$

Where K_i is the capital or sales, S_i and S_g are the country and global saving (not spent income), and V_i and V_g are the country and global stock of unsold goods. The country savings is proportional to its market share M_i :

$$S_i = S_g \cdot M_i \quad (16)$$

In the first case above (equations 13), all goods are sold ($V_i = 0$) and there is no savings ($S_i = 0$), which means the system is in equilibrium; thus $S_g = 0$ and $V_g = 0$. In the second case

(equations 14), there is an excess of demand ($S_g > 0$), there is no inventory ($V_i = 0$) and consumers do not spend all their income, which means savings S_i is added to the global saving and then distributed to countries (equation 16). In the third case (equation 15) there is an excess of supply, stock is positive ($V_i > 0$) and all income is spent ($S_g = 0$).

At steady state, there is no inventory ($V_g = \sum V_i = 0$), which is a first measure of equilibrium in the artificial world economic system. When all countries spend their income, there is no saving ($S_g = \sum S_i = 0$), which means the demand side is also at steady state. Global savings S_g is a second measure of equilibrium.

4. A BASIC ECONOMETRIC ANALYSIS

Table 1 to 4 shows some econometric relationships and models. The GNP is the dependent variable, and patents, articles, and population are the independent variables; all in logarithmic scale. As one can see there are strong relationships among all variables, which means that some “system” (set of iteration / interaction) connects them. Three basic econometric models show these relationships:

$$\text{Model 1: } \text{GNP} = \alpha + \beta_1 \cdot \text{POP} + \beta_2 \cdot \text{PATpc} + \beta_3 \cdot \text{ARTpc}$$

$$\text{Model 2: } \text{GNP} = \alpha + \beta_1 \cdot \text{POP} + \beta_2 \cdot \text{PAT} + \beta_3 \cdot \text{ART}$$

$$\text{Model 3: } \text{GNPpc} = \alpha + \beta_1 \cdot \text{POP} + \beta_2 \cdot \text{PATpc} + \beta_3 \cdot \text{ARTpc}$$

Models 1 and 3 are those with the same basic setup of the model of proposed above. Model 2 is the one with the best fit, although it presents some econometric problem, such as multicollinearity (see table 1 for correlations).

The agent-based model uses the same variable of the econometric model as a determinant of the GNP and GNPpc. Nonetheless, there is an “imitation behavior” represented by the term T_g in the equation 6 that is not a component of the econometric model. The usual proxies for technological capabilities PAT and ART do not capture the imitation capability, and there is no good proxy for such behavior. Thus, the agent-based model introduced the imitation into the determinants of the wealth of nations, and the simulation shows that its relevance.

5. ILLUSTRATIVE SIMULATIONS AND DISCUSSION

The figures below summarize the simulations. Figures 1 and 2 show the fitness of the model when all independent variables are random numbers in the interval $[0, 1]$, except for the population, which is the one of the period 1999-2003. Figures 3 and 4 show the same correlations when the initial technology and income share are random numbers in the interval $[0, 1]$, excluding the population and the NSI, which is given by the equation 6.

Figures 1 and 2 show that, without the NSI, the system is not able to reproduce the levels of GNP and GNP per capita. On the other hand, when NSI is given, the system reproduces the hierarchy of countries as in the data (figure 3 and 4). Figure 5 and 6 show the same runs, however, there is no imitation (the term T_g is dropped from equation 6). The figure 5 shows that the slope of the fit line increases from 1.0977 to 1,3293, which means an overestimation of the hi-tech economies. The change was expected, since in this version of the model the low-tech economies cannot imitate the hi-tech economies (there is no diffusion of technology or spillovers). Regarding the income per capita, there is no significant change in the fitness of

the model. Hence, we can say that imitation and the technological spillovers in an important determinant in technological race and the wealth of nations.

Figure 3 has another important characteristic: the slope of the fit line is 1.0976, which means that the larger and hi-tech economies are overestimated and the smaller economies are underestimated. A possible theoretical explanation for this result is that the model does not take into account the “other factors”, as described by Bernardes & Albuquerque (2003).

Bernardes & Albuquerque (2003) suggest three different “regimes”, ranging from the least developed countries (regime I) to the developed countries (regime III) (figure 9). The model uses four sets of variables: scientific production, technological production, economic growth, and “others” (representing a broad range of factors and variables left out, such as availability of natural resources, health conditions, demographic factors etc.). The mutual feedback between scientific and technological capabilities and growth contribute to explain the share of the countries in the world economy (Fagerberg, 1994; Dosi et al., 1994).

As the country evolves, more connections are “turned on” and more interactions operate (the arrows in figure 7). “Regime III” is the case where all connections and interactions are working. As long as the development takes place, the role of “others” in the causation of economic growth decreases. In other words, as a country upgrades its economic position, its economic growth is more and more a result of its scientific and technological resources. The model proposed above has no proxy for “other factors”; thus those countries with GNP relying on “other factors” would have their share in the world economy underestimated, which is represented by a fit line with slope higher than 1. The difference between 1 and 1.0976 is a broad measure of “other factors”.

(To be continued...)

Table 1: Correlation Matrix

	GNP	GNPpc	POP	PATpc	ARTpc	PAT	ART
GNP	1.0000						
GNPpc	0.3606	1.0000					
POP	0.2689	-0.0786	1.0000				
PATpc	0.6578	0.6752	0.0385	1.0000			
ARTpc	0.2631	0.8053	-0.0726	0.7084	1.0000		
PAT	0.9691	0.3015	0.1550	0.6577	0.2037	1.0000	
ART	0.9869	0.3950	0.2804	0.6743	0.3335	0.9380	1.0000

Table 2: Model 1

Dependent variable: GNP				Independent variables: POP, PATpc, and ARTpc.			
Number of observations = 124				Regression with robust standard errors			
F(3, 120) = 3.97				Prob > F = 0.0098			
R-squared = 0.5574				Root MSE = 7.4e+11			
GDP	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]		
POP	1491.288	557.4114	2.68	0.009	387.652	2594.923	
PATpc	3.80e+15	1.68e+15	2.26	0.026	4.67e+14	7.13e+15	
ARTpc	-2.03e+14	1.30e+14	-1.56	0.122	-4.60e+14	5.50e+13	
CONS	5.96e+10	4.68e+10	1.27	0.206	-3.32e+10	1.52e+11	

Table 3: Model 2

Dependent variable: GNP				Independent variables: POP, PAT, and ART			
Number of observations = 124				Regression with robust standard errors			
F(3, 120) = 1124.55				Prob > F = 0.0000			
R-squared = 0.9909				Root MSE = 1.1e+11			
GDP	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]		
POP	270.844	109.949	2.46	0.015	53.15261	488.5355	
PAT	1.04e+07	1708368	6.09	0.000	7028478	1.38e+07	
ART	5589532	543695.1	10.28	0.000	4513053	6666010	
CONS	1.19e+10	8.46e+09	1.40	0.163	-4.87e+09	2.86e+10	

Table 4 - Model 3

Dependent variable: GNPpc				Independent variables: POP, PATpc, and ARTpc			
Number of observations = 124				Regression with robust standard errors			
F(3, 120) = 52.32				Prob > F = 0.0000			
R-squared = 0.6721				Root MSE = 7335.8			
GDPpc	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]		
POP	-3.30e-06	1.76e-06	-1.88	0.062	-6.78e-06	1.75e-07	
PATpc	1.05e+07	4964409	2.11	0.037	631727.7	2.03e+07	
ARTpc	4134026	645096.4	6.41	0.000	2856780	5411272	
CONS	3448.808	764.9374	4.51	0.000	1934.285	4963.33	

Table 5: Parameters of Simulations

- | |
|---|
| 1 - Country per capita income (2003) |
| 2 - Global income is constant ($Y_g = \sum Y_i$) (2003) |
| 3 - Country population is constant (mean of 1999-2003) |
| 4 - PT_{pci} , standardized by PT_{MAX} (accumulated of 1999 to 2003) |
| 5 - AT_{pci} , standardized by AT_{MAX} (accumulated of 1999 to 2003) |
| 6 - M_{i0} is random number $\in [0, 1]$, where $\sum M_{i0} = 1$ |
| 7 - T_{i0} is random number $\in [0, 1]$ |

Figure 1: Country GNP (Log Scale, US\$, time = 100,000)
(Random values of Pat_i , Art_i , T_{i0} , M_{i0} , and Y_{i0})

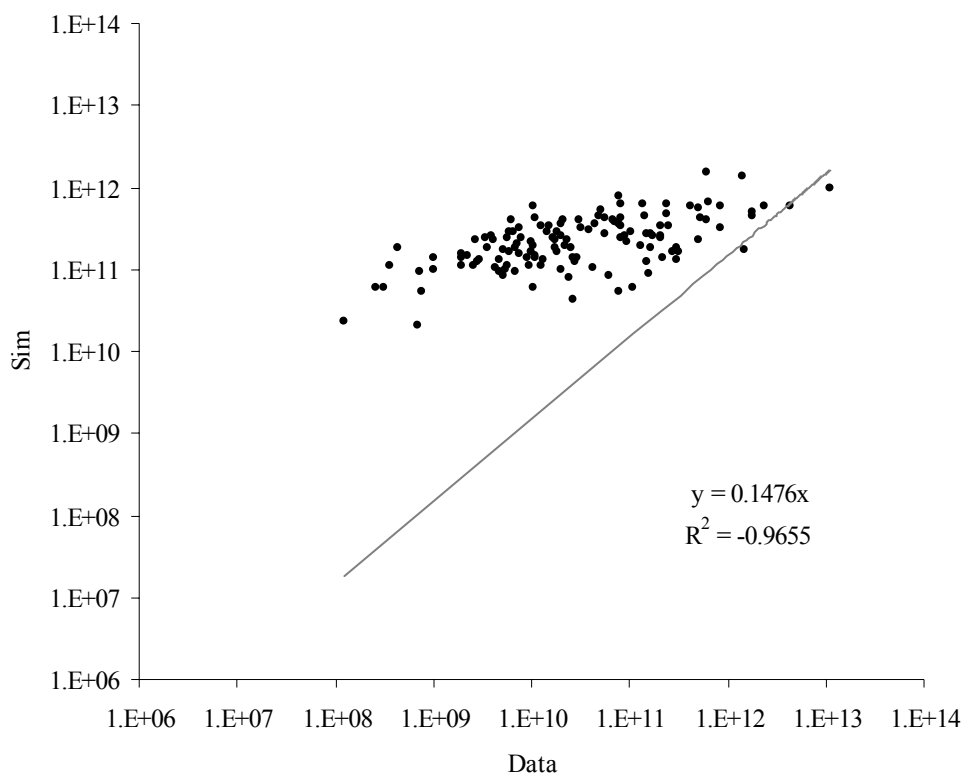


Figure 2: Income Per Capita (Log Scale, US\$, time = 100,000)
(Random values of Pat_i , Art_i , T_{i0} , M_{i0} , and Y_{i0})

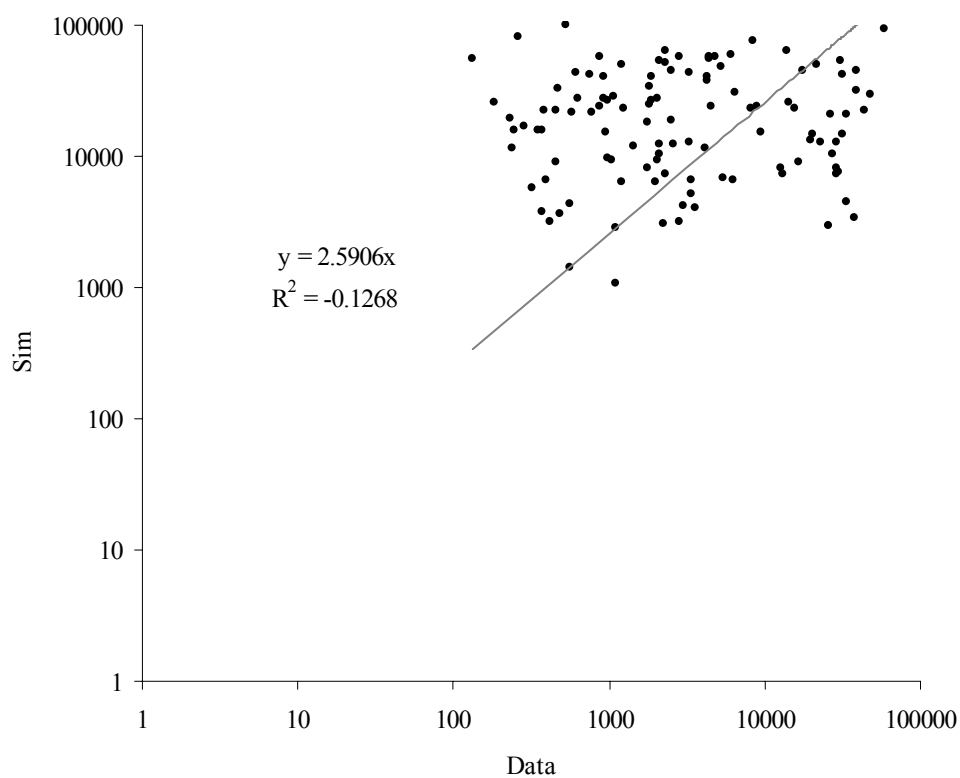


Figure 3: Country GNP (Log Scale, US\$, time = 100,000)
(N_i as given by equation 2 and random values of T_{i0} , M_{i0} , and Y_{i0})

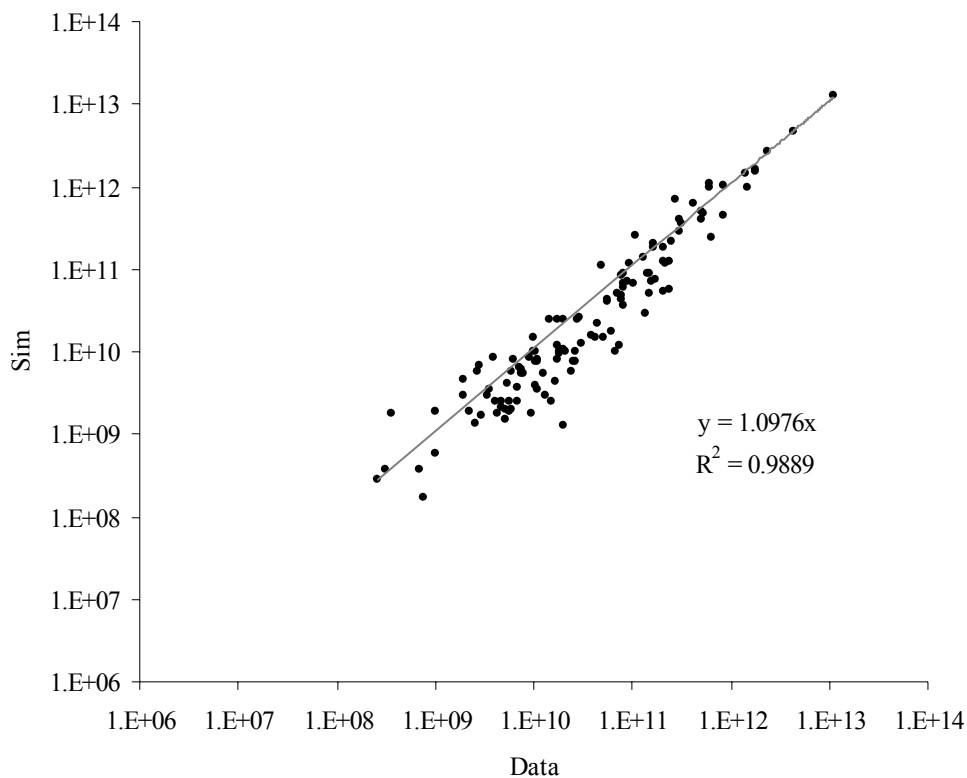


Figure 4: GNP Per Capita (Log Scale, US\$, time = 100,000)
(N_i as given by equation 6 and random values of T_{i0} , M_{i0} , and Y_{i0})

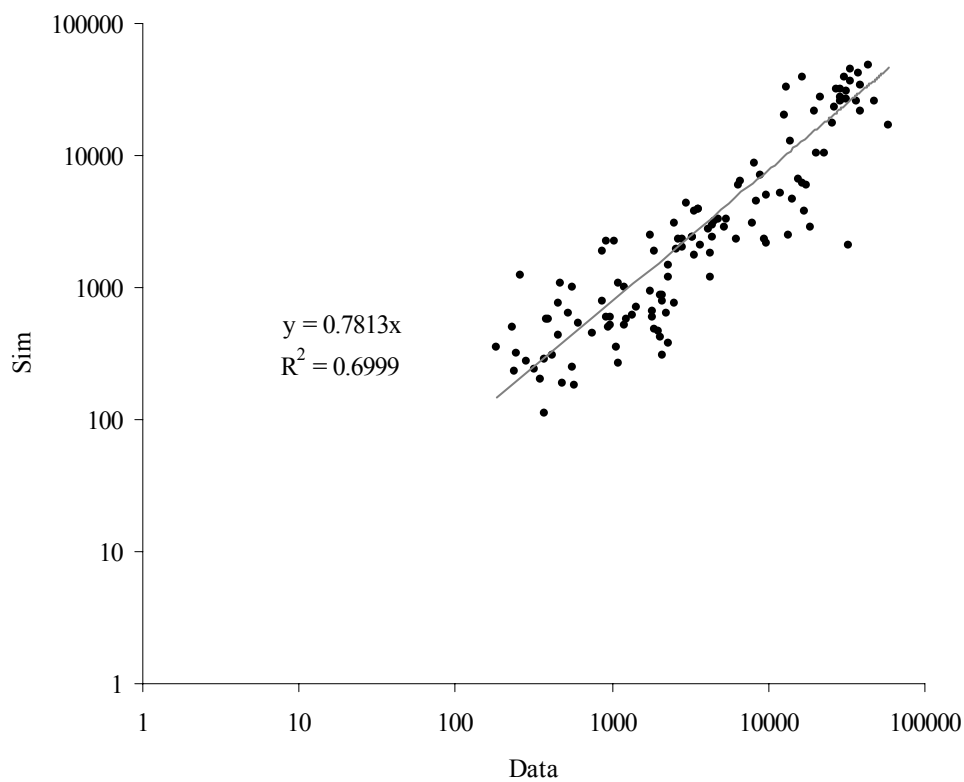


Figure 5: Country GNP (Log Scale, US\$, time = 100,000)
 (N_i without the term T_g , and random values of T_{i0} , M_{i0} , and Y_{i0})

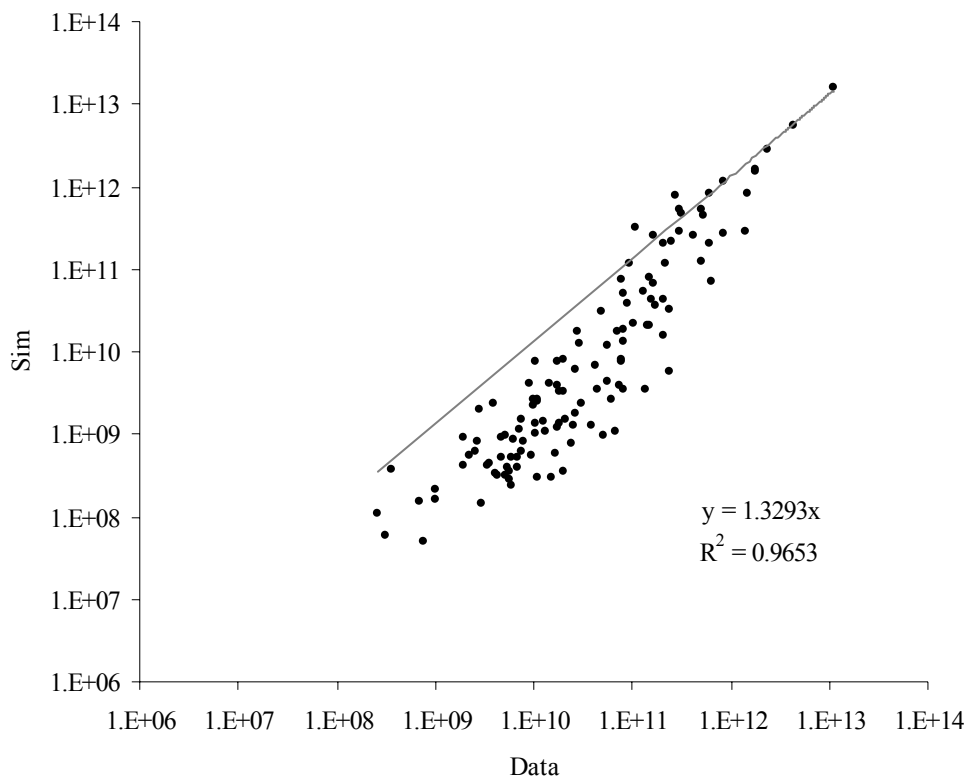


Figure 6: GNP Per Capita (Log Scale, US\$, time = 100,000)
 (N_i without the term T_g , and random values of T_{i0} , M_{i0} , and Y_{i0})

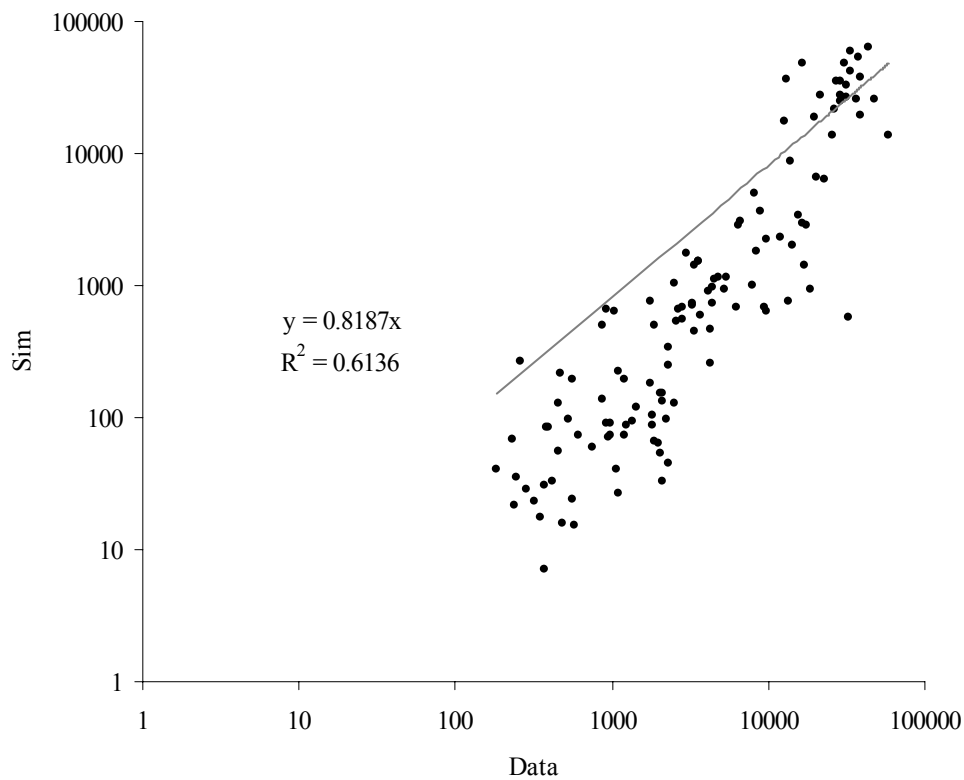


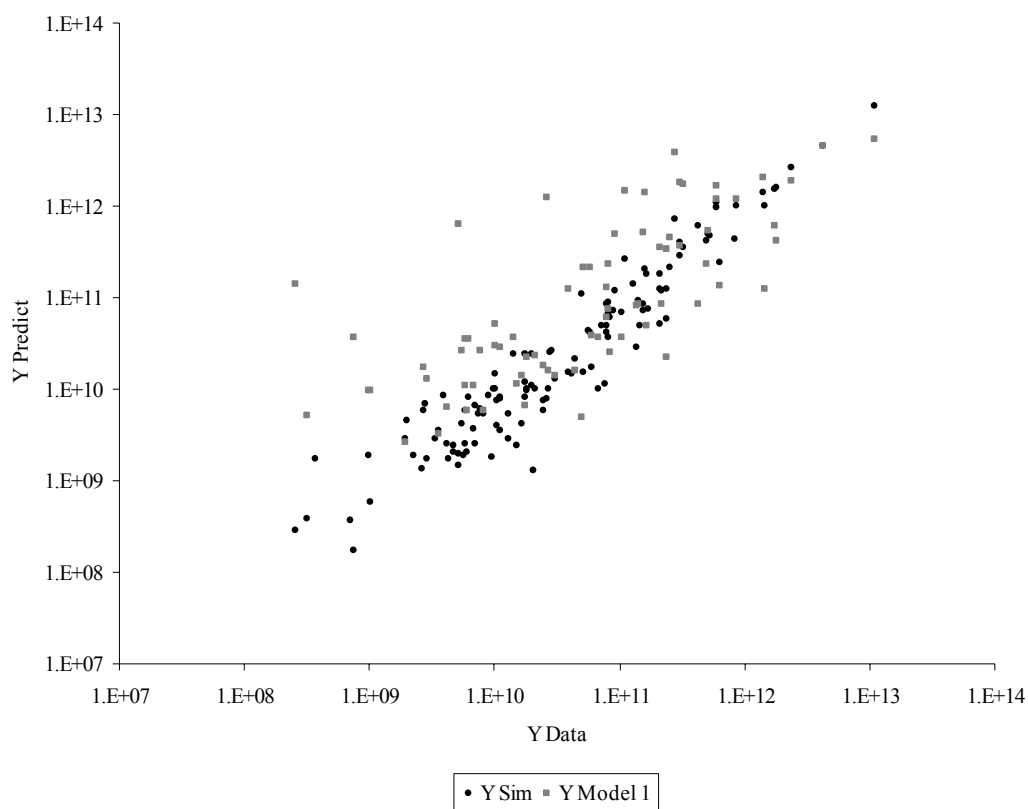
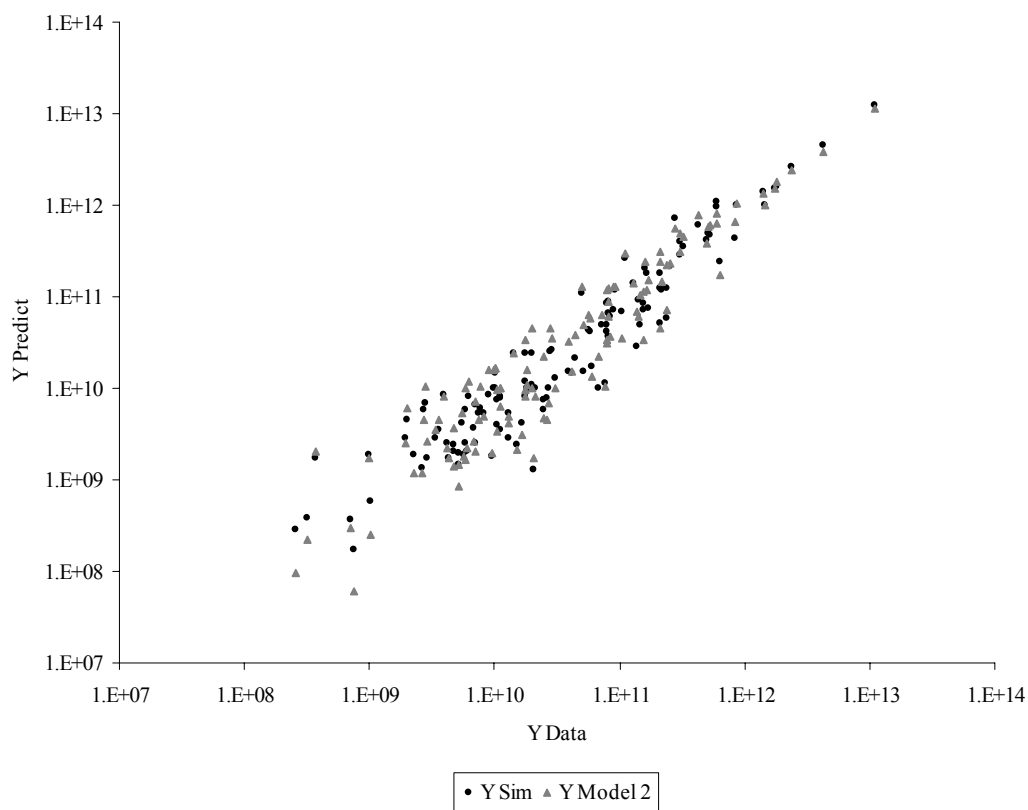
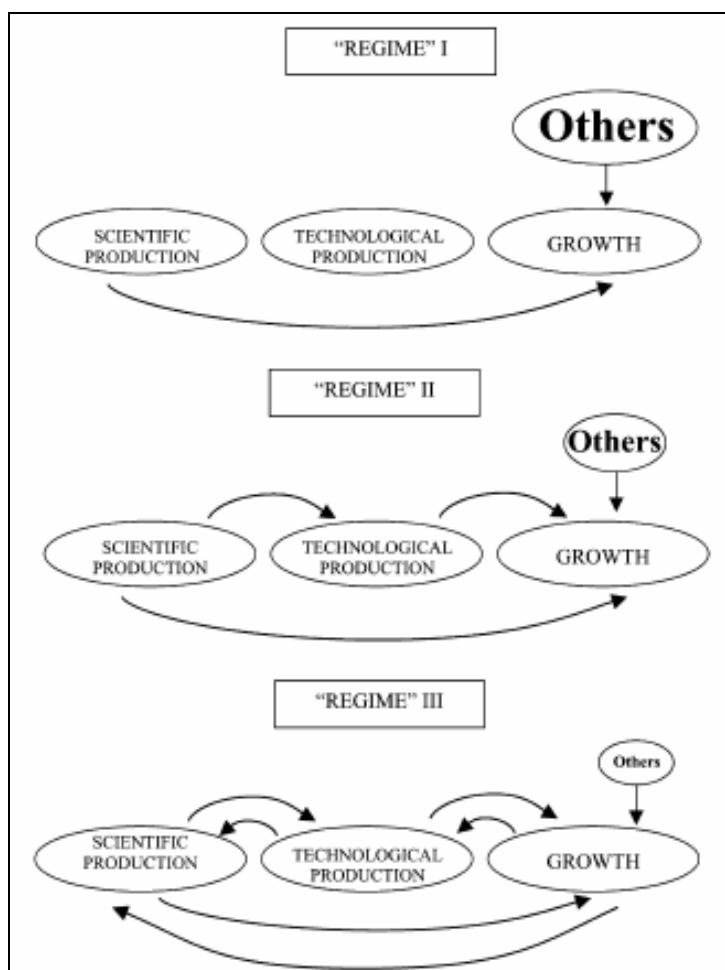
Figure 7: GDP Prediction - Simulation and Econometric Model 1 (ln scale)**Figure 8: GDP Prediction - Simulation and Econometric Model 2 (ln scale)**

Figure 9: The NSI Regimes

Source: Bernardes & Albuquerque (2003)

Appendix 1: Country Data

Country	Population (2003)	Income p.c. (2003)	Patent (1999-2003)	Articles (1999-2003)
1 Albania	3169064.0	1800.1997	1.0	159.0
2 Algeria	31832610.0	2136.7587	1.0	2322.0
3 Angola	13522110.0	1022.4025	0.0	52.0
4 Antigua and Barbuda	78580.0	9662.2423	1.0	5.0
5 Argentina	37869730.0	3422.1464	266.0	21941.0
6 Armenia	3055630.0	917.9135	5.0	1669.0
7 Australia	19881000.0	26275.2139	4046.0	97116.0
8 Austria	8090000.0	31288.7597	2695.0	35529.0
9 Azerbaijan	8233000.0	866.9391	3.0	851.0
10 Bahamas	317413.0	16571.4700	55.0	34.0
11 Bahrain	711662.0	13498.8787	2.0	305.0
12 Bangladesh	138066400.0	376.0050	1.0	1985.0
13 Barbados	270584.0	9707.9983	4.0	185.0
14 Belarus	9880963.0	1783.3879	22.0	5304.0
15 Belgium	10376000.0	29095.6218	3404.0	48840.0
16 Belize	273700.0	3739.0391	2.0	27.0
17 Benin	6720250.0	529.3141	0.0	308.0
18 Bhutan	873663.0	681.7320	0.0	17.0
19 Bolivia	8814158.0	917.7827	3.0	440.0
20 Bosnia and Herzegovina	3832000.0	1819.6234	2.0	165.0
21 Botswana	1722468.0	4371.7317	0.0	464.0
22 Brazil	176596300.0	2863.8568	525.0	56652.0
23 Brunei	356447.0	15064.6000	0.0	156.0
24 Bulgaria	7823000.0	2548.7602	18.0	7540.0
25 Burkina Faso	12109230.0	345.3452	0.0	424.0
26 Burundi	7205982.0	82.6397	0.0	38.0
27 Cambodia	13403640.0	308.3868	0.0	89.0
28 Cameroon	16087470.0	776.4350	0.0	1025.0
29 Canada	31630000.0	27079.4441	17108.0	151612.0
30 Cape Verde	469681.0	1697.5649	0.0	5.0
31 Central African Republic	3880847.0	309.9859	0.0	65.0
32 Chad	8581741.0	303.9210	0.0	45.0
33 Chile	15774000.0	4590.6080	61.0	10203.0
34 China	1288400000.0	1099.4976	990.0	169568.0
35 Hong Kong, China	6816000.0	22758.6379	1080.0	3669.0
36 Colombia	44584000.0	1793.4194	42.0	3120.0
37 Comoros	600142.0	531.4792	1.0	7.0
38 Congo, Dem. Rep.	53153360.0	106.6921	0.0	170.0
39 Congo, Rep.	3757263.0	948.6560	0.0	170.0
40 Costa Rica	4004680.0	4366.2585	27.0	1172.0
41 Cote d'Ivoire	16835420.0	829.4645	0.0	645.0
42 Croatia	4444653.0	6481.9440	55.0	5863.0
43 Cuba	11326000.0	0.0000	26.0	3058.0
44 Cyprus	769954.0	17107.4532	3.0	813.0
45 Czech Republic	10202000.0	8863.3024	132.0	21681.0
46 Denmark	5387200.0	39331.7336	2357.0	37395.0
47 Djibouti	705480.0	885.8763	0.0	3.0
48 Dominica	71213.0	3625.5319	3.0	8.0
49 Dominican Republic	8738639.0	1892.8404	6.0	113.0

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Country	Population (2003)	Income p.c. (2003)	Patent (1999-2003)	Articles (1999-2003)
50 Ecuador	13007940.0	2091.1042	11.0	569.0
51 Egypt	67559040.0	1220.0756	28.0	12455.0
52 El Salvador	6533215.0	2286.8220	4.0	44.0
53 Equatorial Guinea	494000.0	5900.1194	0.0	13.0
54 Eritrea	4389500.0	170.9965	0.0	84.0
55 Estonia	1353000.0	6712.5432	13.0	2736.0
56 Ethiopia	68613470.0	96.9450	0.0	1128.0
57 Fiji	835000.0	2685.7353	4.0	160.0
58 Finland	5212000.0	31058.2987	3673.0	35639.0
59 France	59762000.0	29410.2083	19584.0	232646.0
60 Gabon	1344433.0	0.0000	0.0	280.0
61 Gambia	1420895.0	257.8938	1.0	291.0
62 Georgia	4568000.0	874.8341	9.0	1206.0
63 Germany	82541000.0	29114.7465	53555.0	318198.0
64 Ghana	20669260.0	368.8666	1.0	797.0
65 Greece	11033000.0	15608.0091	109.0	25807.0
66 Grenada	104600.0	4181.6444	0.0	13.0
67 Guatemala	12307090.0	2009.3995	6.0	207.0
68 Guinea	7908905.0	459.0302	1.0	409.0
69 Guinea-Bissau	1489209.0	160.2488	0.0	80.0
70 Guyana	768888.0	964.2861	0.0	56.0
71 Haiti	8439799.0	345.8862	1.0	45.0
72 Honduras	6968512.0	985.5786	5.0	109.0
73 Hungary	10128000.0	8173.4540	255.0	20384.0
74 Iceland	289000.0	36377.0450	74.0	1549.0
75 India	1064399000.0	564.2973	1010.0	89887.0
76 Indonesia	214674200.0	1111.1027	31.0	2165.0
77 Iran	66392020.0	2065.6659	3.0	8702.0
78 Ireland	3994000.0	38487.4477	659.0	18933.0
79 Israel	6688000.0	16481.2848	4729.0	44086.0
80 Italy	57646270.0	25471.0952	8388.0	158657.0
81 Jamaica	2642628.0	2843.4865	7.0	641.0
82 Japan	127573000.0	33712.9168	165999.0	361295.0
83 Jordan	5307895.0	1873.8391	6.0	2469.0
84 Kazakhstan	14878100.0	2072.4191	11.0	994.0
85 Kenya	31915850.0	450.4280	13.0	2607.0
86 Kiribati	96377.0	605.9537	0.0	0.0
87 Korea, Rep.	47911730.0	12692.5996	18144.0	77758.0
88 Kuwait	2396417.0	17421.1416	39.0	2499.0
89 Kyrgyz Republic	5052000.0	379.8521	2.0	185.0
90 Lao PDR	5659834.0	368.8280	1.0	0.0
91 Latvia	2321000.0	4770.6377	9.0	1660.0
92 Lebanon	4497669.0	4423.2975	15.0	1481.0
93 Lesotho	1792744.0	600.4817	0.0	30.0
94 Liberia	3373542.0	131.0788	0.0	10.0
95 Libya	5559289.0	4220.8777	0.0	251.0
96 Lithuania	3454000.0	5315.5133	8.0	2664.0
97 Luxembourg	448000.0	59143.2188	167.0	470.0
98 Macedonia	2049000.0	2277.4358	1.0	543.0

Appendix 1: Country Data

Country	Population (2003)	Income p.c. (2003)	Patent (1999-2003)	Articles (1999-2003)
99 Madagascar	16893900.0	324.0261	3.0	106.0
100 Malawi	10962010.0	155.1894	0.0	496.0
101 Malaysia	24774250.0	4187.2846	216.0	4699.0
102 Maldives	293080.0	2356.9708	0.0	10.0
103 Mali	11651500.0	373.0000	0.0	221.0
104 Malta	399000.0	11951.1679	8.0	214.0
105 Marshall Islands	57000.0	1839.5614	2.0	0.0
106 Mauritania	2847869.0	415.1933	0.0	73.0
107 Mauritius	1222188.0	4288.5849	1.0	200.0
108 Mexico	102291000.0	6247.6186	411.0	24749.0
109 Moldova	4237600.0	467.4429	2.0	857.0
110 Mongolia	2479568.0	513.9851	0.0	221.0
111 Morocco	30112640.0	1452.1015	5.0	5213.0
112 Mozambique	18791420.0	229.9227	0.0	166.0
113 Myanmar	49362500.0	0.0000	0.0	94.0
114 Namibia	2014546.0	2120.0077	1.0	200.0
115 Nepal	24659960.0	237.2600	1.0	583.0
116 Netherlands	16221800.0	31531.7694	6536.0	88059.0
117 New Zealand	4009200.0	19856.5686	620.0	19371.0
118 Nicaragua	5480000.0	754.5954	2.0	109.0
119 Niger	11762250.0	232.2190	6.0	215.0
120 Nigeria	136461000.0	422.2578	11.0	3638.0
121 Norway	4562000.0	48411.6171	1241.0	23100.0
122 Oman	2598832.0	8349.2546	0.0	1130.0
123 Pakistan	148438800.0	554.7737	8.0	3157.0
124 Palau	19700.0	6289.3401	0.0	14.0
125 Panama	2984022.0	4310.2899	7.0	568.0
126 Papua New Guinea	5501871.0	622.4652	1.0	344.0
127 Paraguay	5643097.0	1068.5313	1.0	111.0
128 Peru	27148000.0	2231.3615	14.0	1027.0
129 Philippines	81502620.0	973.3393	61.0	1852.0
130 Poland	38196000.0	5486.1993	76.0	52282.0
131 Portugal	10444000.0	14161.1505	51.0	17466.0
132 Puerto Rico	3898443.0	17681.5400	104.0	0.0
133 Qatar	623703.0	32749.7206	1.0	268.0
134 Romania	21744000.0	2619.1609	28.0	9835.0
135 Russian Federation	143425000.0	2998.8867	1000.0	128480.0
136 Rwanda	8395000.0	200.5691	0.0	38.0
137 Samoa	178000.0	1784.8034	0.0	20.0
138 Sao Tome and Principe	157400.0	378.7103	0.0	0.0
139 Saudi Arabia	22528300.0	9436.1907	72.0	6859.0
140 Senegal	10239850.0	633.2669	0.0	864.0
141 Serbia and Montenegro	8136000.0	2539.9854	0.0	0.0
142 Seychelles	83639.0	8403.8307	1.0	47.0
143 Sierra Leone	5336568.0	185.4997	3.0	31.0
144 Singapore	4250000.0	21733.9176	1495.0	19320.0
145 Slovak Republic	5390000.0	6065.4879	24.0	0.0
146 Slovenia	1995000.0	13909.1990	81.0	7637.0
147 Solomon Islands	456645.0	516.9902	0.0	43.0

Appendix 1: Country Data

Country	Population (2003)	Income p.c. (2003)	Patent (1999-2003)	Articles (1999-2003)
148 Somalia	9625918.0	128.0300	0.0	3.0
149 South Africa	45828700.0	3609.8372	566.0	17173.0
150 Spain	41101430.0	20404.4578	1373.0	112349.0
151 Sri Lanka	19231760.0	948.7640	4.0	928.0
152 St. Lucia	160588.0	4319.7499	0.0	7.0
153 St. Vincent / the Grenadines	109164.0	3447.0705	0.0	2.0
154 Sudan	33545730.0	530.3681	0.0	452.0
155 Suriname	438104.0	2329.4400	3.0	0.0
156 Swaziland	1105525.0	1721.9285	0.0	59.0
157 Sweden	8956000.0	33676.3826	7915.0	72533.0
158 Switzerland	7350000.0	43553.5003	6693.0	66525.0
159 Syrian Arab Republic	17384490.0	1235.0228	8.0	581.0
160 Taiwan	21780000.0	12943.0670	24460.0	52952.0
161 Tajikistan	6360000.0	244.1613	0.0	88.0
162 Tanzania	35888960.0	286.9075	2.0	1094.0
163 Thailand	62014220.0	2305.1694	128.0	7199.0
164 Timor-Leste	877000.0	382.7822	0.0	0.0
165 Togo	4861493.0	361.8121	0.0	148.0
166 Tonga	101524.0	1659.9129	0.0	13.0
167 Trinidad and Tobago	1312664.0	8007.4414	7.0	526.0
168 Tunisia	9895201.0	2530.2498	1.0	3336.0
169 Turkey	70712000.0	3399.3642	61.0	34917.0
170 Turkmenistan	4863500.0	1200.2543	6.0	43.0
171 Uganda	25280000.0	249.0746	2.0	793.0
172 Ukraine	48355700.0	1036.7538	99.0	20410.0
173 United Arab Emirates	4031000.0	18902.4600	18.0	1640.0
174 United Kingdom	59329000.0	30252.9680	18668.0	275933.0
175 United States	290810000.0	37648.4540	431453.0	1171825.0
176 Uruguay	3380177.0	3310.7077	8.0	1570.0
177 Uzbekistan	25590000.0	395.7840	6.0	1623.0
178 Vanuatu	210164.0	1313.4076	0.0	32.0
179 Venezuela	25674000.0	3249.8162	141.0	4971.0
180 Vietnam	81314240.0	481.6321	2.0	1750.0
181 Yemen, Rep.	19173160.0	573.8182	1.0	173.0
182 Zambia	10402960.0	416.7316	0.0	370.0
183 Zimbabwe	13101750.0	1365.3000	3.0	1039.0

Data Sources:

The source of data on population and GDP per capita is the World Development Indicators on-line database. The source of data on articles per capita is the ISI site. The source of data on patents is the USPTO site.

Notes:

The following countries have different data:

- Brunei: GDP of 1998;
- Puerto Rico: GDP of 2001;
- Somalia: GDP of 1990;
- Taiwan: GDP of 2002 (Taiwan government agency) and population of 1998 (Maddison, 2001);
- United Arab Emirates: 2002 GDP;
- Zimbabwe: 2002 GDP.

Appendix 2: Program**Run-world (main loop)**

set Yglobal 0.00	
ask countries [price-production]	Routine 1
global-competitiveness	Routine 2
ask countries [market-share]	Routine 3
set Sglobal 0.00	
set Vglobal 0.00	
ask countries [demand-sales]	Routine 4
ask countries [savings]	Routine 5
normalize-T	Auxiliary Routine
set time time + 1	

Price-production (routine 1)

```

set Y (K + S)
set Yglobal (Yglobal + Y)
set Q (T * Pop) + V
set P (Y / Q)
set C (1.000 / P)
set T [T + (Tglobal * Pat * Art) ^ (1 / 3)]

```

Global-Competitiveness (routine 2)

```

set Cglobal (sum values-from countries [C * M])
set Tglobal (sum values-from countries [T * M])

```

Market-share (routine 3)

```

set M [M * {1.000 + Speed * ((C / Cglobal) - 1.000)}]

```

Demand-sales (routine 4)

```

set D (M * Yglobal / P)
if D = Q [set K (P * D)
  set V 0.00
  set Sglobal (Sglobal + 0.00)
  set Vglobal (Vglobal + V)]
if D > Q [set K (P * Q)
  set V 0.00
  set Sglobal (Sglobal + (P * (D - Q)))
  set Vglobal (Vglobal + V)]
if D < Q [set K (P * D)
  set V (Q - D)
  set Sglobal (Sglobal + 0.00)
  set Vglobal (Vglobal + V)]

```

Savings (routine 5)

```

set S (Sglobal * Y / Yglobal)

```

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