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**Working Paper**

## The future development of world records

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Faculty of Business,  
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Chair for Economic Policy

FRANZISKA K. KRUSE / WOLFGANG MAENNIG

# THE FUTURE DEVELOPMENT OF WORLD RECORDS

NIKO

NIKO

Urban  
Transport  
Media  
Sports  
Socio-  
Regional  
Real Estate  
Architectural

HAMBURG CONTEMPORARY

ECONOMIC DISCUSSIONS

NO. 61

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## The future development of world records

**Abstract:** We conduct an innovative analysis of sporting world records by a) using economic instead of sporting determinants and b) by using multivariate stochastic frontier functions. Using data from 48 different disciplines between 1970 and 2014, we show that world records are close to full efficiency and therefore actual athletic frontiers. Forecasts including economic determinants imply that the dynamics of world records largely depend on the dynamics of the frontiers and their driving forces, i.e., socio-economic developments.

*Keywords:* World records, productivity growth, stochastic frontier function, technical efficiency

*JEL:* C10, C23, C53, L83

*Version:* September 2017

### Introduction

New world records have become less frequent (see, for example, the table of valid world records for track and field disciplines (IAAF, 2017c)). In recent decades, athletes have been fighting to break world records that were set years, if not decades, ago. It is occasionally argued that world records set in the 1990s and before may result from doping and can barely be broken by today's athletes who are under more effective doping control.<sup>1</sup> In other words, the athletic productivity of earlier decades is mis-measured, and athletic productivity in recent times relative to earlier times is biased downward.

However, parallel to this athletic stagnation, economic productivity growth in leading countries decreased significantly in recent decades. In the US/GB/Germany, average productivity growth was at + 2.7%/2.5%/1.6%, respectively, from 2000 to 2007 and

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<sup>1</sup> The International Association of Athletics Federations, IAAF, decided to scrap the existing world records that were achieved before 2005 and start over with new, and "clean", world records, IAAF (2017a)).

decreased to +1.1%/1.2%/+1.3%, respectively, from 2008 to 2017.<sup>2</sup> There is, as with athletics, a discussion of the measurement problems of economic productivity.<sup>3</sup>

Economic and productivity growth have been investigated for many decades, including the pioneering contributions of (Solow, 1956), (Romer, 1986) and (Lucas, 1988). Nearly all empirical studies find real GDP, population growth, and trade openness to be significant determinants of economic growth and productivity growth (e.g., (Afonso & Jalles, 2013), (Danquah, Moral-Benito, & Outtara, 2014), (Barro, 1991) and (Miller & Upadhyay, 2000)).

Note that similar determinants were also found to be of significance for Olympic medal rankings. Publications as early as those of (Jokl, 1964), (Grimes, Kelly, & Rubin, 1974) as well as more recent ones such as (Bernard & Busse, 2004), (Johnson & Ali, 2004), and (Forrest, Sanz, & Tena, 2010) find that GDP per capita and population size impact Olympic sporting success. A larger population implies a larger pool of talents, and larger real GDP per capita may imply larger funds for the support of athletes, both facilitating better athletic achievements.

This paper analyzes world record developments on the broadest available basis of sporting disciplines and contributes to the world record literature as it begins from the assumption that economic productivity growth and that world record developments are driven by similar determinants. Earlier contributions on world records such as that by (Kuper & Sterken, 2007), (Hanly, Sharp, & Friskin, 2012), (Péronnet & Thibault, 1985) and (Volf, 2011) focus on the functional (model) form and the statistical distributions of modeling world records or use determinants such as population size (Haake, Foster, & James, 2014). Conversely, (Chang & Baek, 2011) analyze the remaining time in years for world records to encounter a limit; however, none of these contributions include

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<sup>2</sup> Data were retrieved from the US Bureau of Labor Statistics (U.S. Bureau of Labor Statistics (2017), OECD Database (OECD (2017)) and Statistisches Bundesamt (2017)).

<sup>3</sup> It has been noted that this may be a mismeasurement problem, particularly an underestimation of productivity growth in the computer industry (Byrne, Fernald, and Reinsdorf (2016)). To capture the various and, in several cases, unobservable aspects of productivity, different productivity indices were introduced, see Malmquist (1953) and Moorsteen (1961)).

economic determinants to explain the progression of world records. We forecast world records conditional on economic variables and find that world records are close to efficiency frontiers, unless new technologies may enter the picture.

Section 2 describes the data and the empirical strategy. Section 3 presents the results of our frontier approach and discusses our forecasts. Section 4 concludes.

## **Data and empirical strategy**

We collected a database of world records for all disciplines, using official world record websites (International Association of Athletics Federations ((IAAF, 2017b), Fédération Internationale de natation (FINA, 2017), International Skating Union ((ISU, 2017) and Union Cycliste Internationale (UCI, 2017)) and measuring world records by time in seconds. A discipline was dismissed if there was no officially validated world record (e.g., triathlon). We restricted the sample to 1970-2014, due to the availability of control variables, and excluded disciplines that experienced significant changes in regulations. For disciplines with both indoor and outdoor records, we focus on the indoor records. Swimming data are obtained from the Olympic long course (50 meters) data set, which is historically older than the short track (25 meters). The full list of disciplines is displayed in Table A1. The list includes 19 disciplines in running, two disciplines in walking, 17 different kinds of swimming disciplines, six speed skating disciplines and four track cycling disciplines. If the records showed various observations for one discipline in one year, in other words, when the world record was renewed more than one time in a year, we used the fastest of all the observations in that year.

We collected data for women's and men's world records. However, since the variance in women's records is small and the women's world records include fewer data points, a stochastic frontier analysis did not converge. Therefore, we needed to restrict ourselves to the analysis of men's world records.

For the selection of control variables, we utilize the insights of the literature of economic growth and use yearly data of GDP per capita, population and exports (in % of GDP) ((Barro, 1991), (Baltabaev, 2014), (Afonso & Jalles, 2013) and (Danquah et al., 2014)). Data for the real GDP per capita were collected from the World Penn Tables 9.0 (Feenstra, Inklaar, & Timmer, 2015)). Data for exports and population were taken from the World Bank Data Bank (World Bank, 2017)). The aggregates are calculated from the data of 13 of the 15 with the largest medal success in the Summer and Winter Games 2002-2016, winning 73% of all gold medals (Table A2 in the appendix). Russia and the Ukraine needed to be excluded as no complete economic data sets were available.

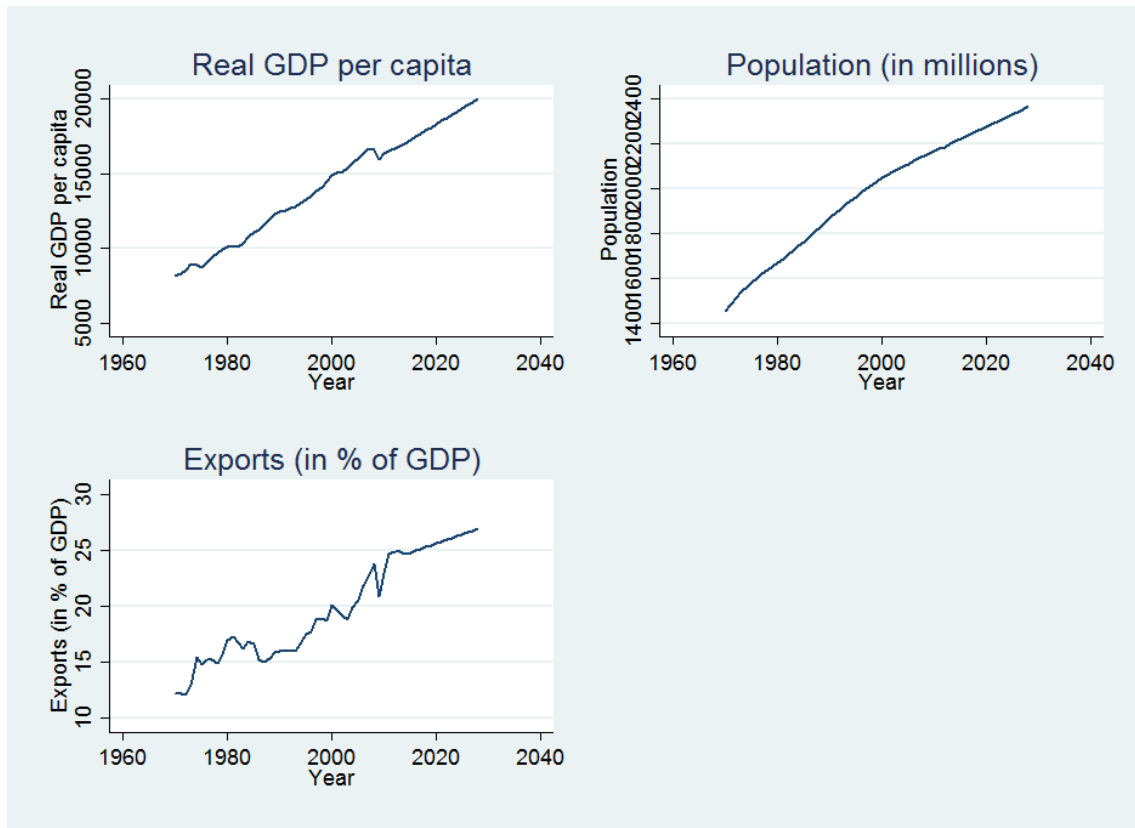
The descriptive statistics for the control variables are represented in table 1 and figure 1.

**Table 1 Descriptive statistics of control variables**

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Exports (in % of GDP)	45	17.87	3.44	12.10	24.85
Population	45	1.88 e <sup>08</sup>	2.28e <sup>08</sup>	1.46e <sup>09</sup>	2.21e <sup>09</sup>
Real GDP per Capita	45	12,739.32	2,846.13	8,149.18	17,034.06

Sources: Data basis: World Bank (2017), Center for International Comparisons at the University of Pennsylvania (CICUP, 2006); own calculations.

**Figure 1 The dynamics of control variables**



Note: Figure 1 and table 1 display the descriptive statistics of three time series of control variables used in the empirical analysis. Exports are provided in % of GDP. Population and real GDP per capita are absolute numbers.

We estimate a true random effects stochastic frontier model for panel data ((Aigner, Lovell, & Schmidt, 1977), (Greene, 2005)). This model is used when the data are panel data and when the constant can be assumed to be random. In accordance with (Fair, 1994) and (Maennig & Stobernack, 2011), we include all dependent and independent variables as natural logs in the analysis (except year and year<sup>2</sup>). In order to connect our analysis to earlier studies such as size (Haake et al., 2014), we start by regressing the natural logarithm of the world record times (in seconds) on year and year<sup>2</sup> (normalizing the years to 1970 = 1), as well as the natural logarithm of population. The inclusion of the additional control variables in the equation leads to a multicollinearity problem that is displayed in the variance-covariance-matrix of the estimates in table A3. Since real GDP per capita and the year variables are highly collinear,<sup>4</sup> we excluded the year variables for

<sup>4</sup> The augmented Dickey-Fuller-Test suggests that all our control variables are stationary with a trend.



further analyses. In addition, real GDP per capita and population are highly collinear. Therefore, we first include population in the analysis to confirm the “negative” impact of population from the earlier contributions noted above. Thereafter, we dismiss population and include our economic variables. The estimation equations read as follows:

$$M1: \ln(\text{time})_{it} = (\alpha_0 + \omega_i) + \beta_1 \ln(\text{population})_{it} + \varepsilon_{it}$$

$$M2: \ln(\text{time}) = (\alpha_0 + \omega_i) + \beta_1 \ln(\text{real GDP per capita})_{it}$$

$$M3: \ln(\text{time}) = (\alpha_0 + \omega_i) + \beta_1 \ln(\text{real GDP per capita})_{it} + \beta_2 \ln(\text{exports}),$$

all specifications with

$$\varepsilon_{it} = v_{it} - u_{it}, i = 1, \dots, N,$$

$$u_{it} \sim \mathbb{N}^+(0; \sigma_{it}^2) = \mathbb{N}^+(0, \exp(\omega_{u0} + z'_{u,it} \omega_u)),$$

$$v_{it} \sim \mathbb{N}(0, \sigma_v^2),$$

$$\omega_i \sim \mathbb{N}(0, \sigma_\omega^2),$$

This symmetric normal and half-normal distribution of the error terms helps to define the frontier in an appropriate manner (Aigner et al., 1977)). (Greene, 2005) focuses on the modeling of the inefficiency that can be calculated from the model to overhaul the shortcomings of the original model of (Aigner et al., 1977), since, in this specification, the mean and variance of  $u_{it}$  can depend on variables that are time-invariant. The constant is also treated as random in this model (Greene, 2005), (Kumbhakar, Lien, & Hardaker, 2012)).

## **World record developments, 1970–2014: Results and discussion**

Column 2 in Table 2 displays the results with  $\ln(\text{population})$  as only explanatory variable. In further steps, we test the log of real GDP per capita (column 3) as well as the logarithm

of exports (in % of GDP) (column 4). The conduction of each analysis includes 10,000 pseudo random draws.<sup>5</sup>

**Table 2 World records; stochastic frontier estimates**

Ln(time)	Model 1 (M1)	Model 2 (M2)	Model 3 (M3)
Constant	12.10835*** (.0541974)	10.6563*** (.0173155)	9.339705*** (.0245242)
Ln(population)	-.206544*** (.0025309)		
Ln(real GDP per capita)		-.1119436*** (.0017988)	-.1044162*** (.0037256)
Ln(exports)			-.0073345* (.0045232)
Number of observations	2068	2068	2068
Number of groups	48	48	48
Log simulated likelihood	5047.2641	4962.8966	5061.6737
Wald Chi <sup>2</sup>	6659.78	3872.82	4133.85
Prob > Chi <sup>2</sup>	0.0000	0.0000	0.0000
AIC	-10,084.53	-9915.793	-10111.35
BIC	-10,056.47	-9887.621	-10077.54

Standard errors are in parentheses. \*\*\*/\*\*/\* = significant at the 1/5/10% level, respectively.

According to the Akaike and Bayesian information criteria, the model specification M2 has the lowest information quality compared to the other models. Information criteria for M1 and M3 are within the same range. Since we focus on economic and not demographic variables, we choose M3 as the preferred model specification. The Wald-test, with its p-value, suggests that at least one coefficient is not equal to zero in each model specification, and that that the models are (highly) significant.

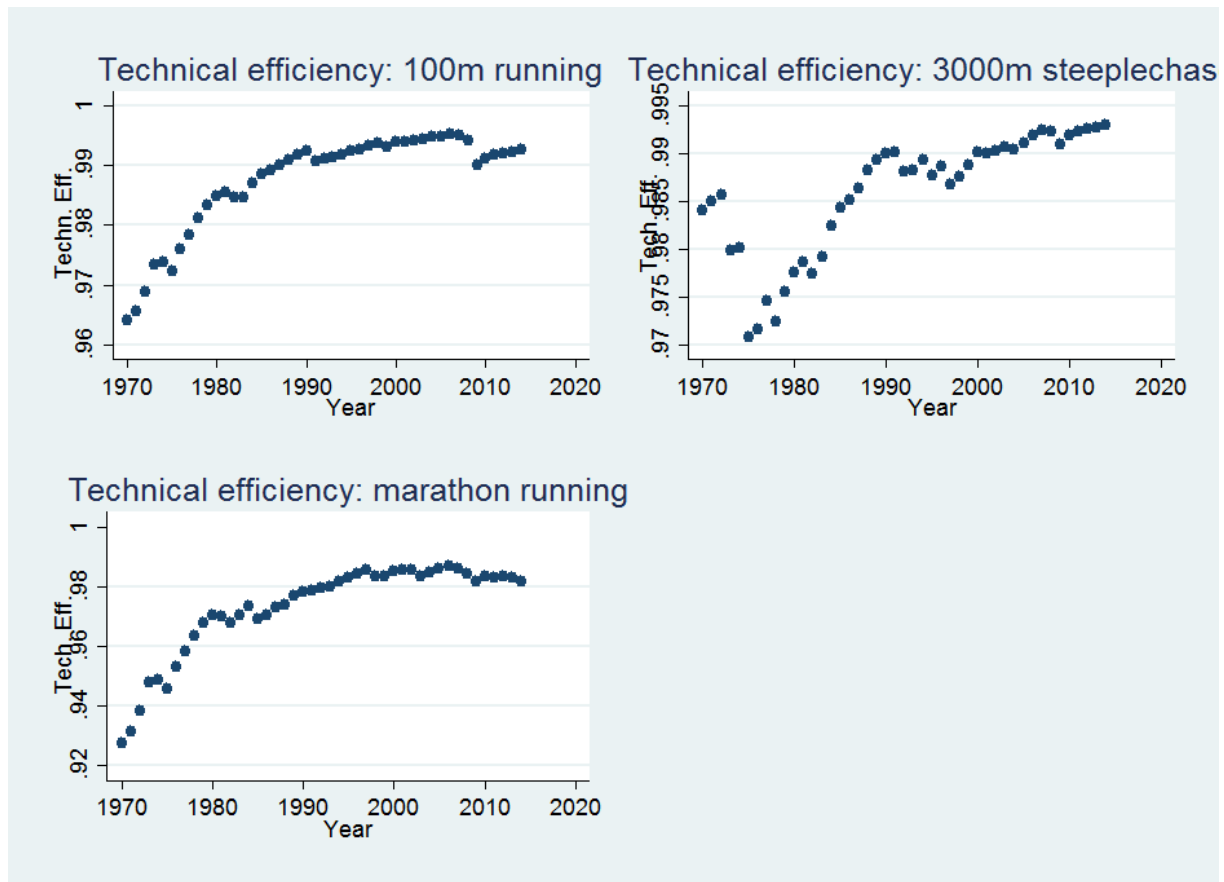
In model specification M1, we replicate the results of (Haake et al., 2014) by confirming the “negative” impact of population on world record times. If the population is growing, the pool of talents is growing, implying a larger likelihood that world records may be broken. In M2, we include real GDP per capita exclusively, due to the issues noted above.

<sup>5</sup> The results are robust to an increase in draws.

In this model specification as well as in M3, real GDP per capita does have a significantly negative coefficient in all models, implying a positive impact on athletic performance. In the last specification, we add exports. The estimated coefficient is significantly negative (on a 10\*-level); higher exports represent a higher degree of openness of countries trading new technologies and knowledge between each other. This exchange can positively influence the world record times attained, since athletes may be able to use these traded goods to improve their performance.

On the basis of model specification M3, we calculated the technical efficiency of the world record of each discipline according to the frontier analysis. The progress of the estimated technical efficiencies of the selected disciplines is displayed in figure 2, in % of athletic-technological frontiers.

**Figure 2 Technical efficiency of selected disciplines, in % of technical frontiers**



The graphical illustration emphasizes that certain disciplines are close to their current frontier (the technical efficiency of the 100-m dash and marathon are currently at 0.992/0.981, respectively, in 2014). A technical efficiency of 1 (or near one) indicates that world records are very near or are at the frontier.

### **Forecasting world records**

Next, we perform out-of-sample forecasting for the regressors and the dependent variable. Since the real GDP per capita, population and exports (in % of GDP) are showing an upward trend in the data, we used the non-seasonal Holt-Winter forecasting method ((Winters, 1960), (Chatfield, 1978), among others). We transformed the forecasted variables in the same manner as in the first analysis to forecast new world record times and the technical efficiency.

We could not forecast several disciplines since their estimations did not converge (potentially due to minimal variance in the data). For the remaining disciplines, a point forecast was estimated for 2022 (table 3). Our starting point in 2014 is the existing world record.

**Table 3 Out-of-sample forecasting and technical efficiency for selected disciplines**

Discipline	Constant	Ln(real GDP per capita)	Ln(exports)	Time (in seconds) 2014	Technical Efficiency	Forecasted time in 2022	Technical Efficiency
Running 100 m	2.609316*** (6.16e-06)	-0.025522*** (9.06e-07)	-0.026705*** (1.34e-06)	9.58	.9856839	9.56	0.9947168
Running 1 Mile	5.959913*** (.0291422)	-.0590554*** (.0041037)	.007191* (.0042049)	223.13	.998641	222.07	.9988881
3000-m steeplechase	6.674914*** (.0464893)	-.0430587*** (.0071878)	-.0316784*** (.0087717)	473.63	.9999	467.87	.999907
400-m hurdles	4.186533*** (.0380824)	-.0377411*** (.0058674)	.0072792 (.0071603)	46.78	.9999081	46.48	.999907
Speed Skating 1500 m	6.807781*** (.1305647)	-.1912672*** (.0202)	-.1045627*** (.0246512)	101.04	.9997429	98.08	.9997402
Swimming 800-m freestyle	7.085062*** (.1020592)	-.0838685*** (.0157984)	-.0491433*** (.0192798)	452.12	.999814	445.86	.999814
Swimming 50-m backstroke	3.327085*** (.0985235)	.0356222** (.0149812)	-.1278487*** (.0004963)	24.04	.991375	23.97	0.995074

Note: Standard errors are in parentheses. \*\*\*/\*\*/\* = significant at the 1/5/10% level, respectively.

According to Tab. 3, world records of the 1-mile run, 3000-m steeplechase, and 50-m backstroke swimming may further approach the technical efficiency limits of 1 until 2022, indicating a reduced potential for world record improvements beyond the general economic growth as long as no extraordinary technical change (e.g., doping or a major reformation in technologies) arise. This finding is outstanding for the 3000-m steeplechase, which had a high technical efficiency previously in 2014. For the 100-m dash, 400-m hurdles, and 1500-m speed skating, our forecasts imply new world records but a decreasing technical efficiency. Thus, the shift of the frontier is forecasted to be larger than the dynamics of the world records.<sup>6</sup>

<sup>6</sup> For the 400 m hurdles running, we find that the coefficient for exports is not significant. For our forecast of future world records, we neglected such non-significant variables.

We forecast the largest improvement for world records for speed skating (improvement of world record time of 2.92% until 2022). The least dynamic discipline, the 100-m dash, enjoys a forecasted improvement of 0.2% of the world record time.

## **Conclusion**

We conduct an innovative analysis and forecast athletic world records by using economic variables and demonstrated that athletic and economic productivity are driven by similar determinants, also implying potential parallels in their future developments. We show that most current world records are close to their technological/ athletic frontier. World record improvements will largely depend on the extent of the growth in technical frontiers, i.e., of determinants that drive economic growth as well. If those determinants only display a limited dynamic (as is suggested by the economic growth literature and by our forecasts), a slowing of the dynamic of world records may be expected as well.

There are certain caveats. If there are major technological changes and hidden abuses of medical and pharmaceutical progress that are not in accordance with general economic progress, such as a revolution in the bikes for track cycling, our result may be biased downward.

There is one more insight from our analysis that may motivate further research: The low rates of economic productivity growth in Western economies in recent years are less surprising if contrasted with athletic developments.

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## Appendix

**Table A1 Disciplines with sound world records included in our analysis**

<b>Running</b>	<b>Track cycling</b>
60 m	
100 m	200 m
200 m	500 m
400 m	1000 m
800 m	4000 m
1000 m	
1500 m	
1 mile	
3000 m	
3000-m steeplechase	
2 miles	
5000 m	
10,000 m	
21.1 km	
42.2 km	
110-m Hurdles	
400-m Hurdles	
4x100-m relay	
4x400-m relay	
20-km walking	
50-km walking	
<b>Swimming</b>	<b>Speed skating</b>
50-m freestyle	500 m
100-m freestyle	1000 m
200-m freestyle	1500 m
400-m freestyle	3000 m
800-m freestyle	5000 m
1500-m freestyle	10000 m
50-m backstroke	
100-m backstroke	
200-m backstroke	
50-m breast stroke	
100-m breast stroke	
200-m breast stroke	
50-m butterfly	
100-m butterfly	
200-m butterfly	
4x100-m relay	
4x200-m relay	

**Table A2 Proportions of gold, silver and bronze medals won in all (Summer and Winter) Games from 2002-2016 per country**

Proportions of medals in all Games from 2002 – 2016	Overall	Gold	Silver	Bronze
1. USA	11,96%	12,88%	11,96%	11,04%
2. Russia	8,15%	7,75%	7,46%	9,25%
3. China	7,71%	10,19%	6,23%	6,68%
4. Germany	6,21%	6,28%	6,56%	5,78%
5. UK	4,64%	5,58%	4,12%	4,24%
6. France	4,20%	3,33%	4,37%	4,88%
7. Australia	3,64%	3,33%	3,86%	3,72%
8. Canada	3,49%	3,14%	3,41%	3,92%
9. Japan	3,36%	2,95%	2,89%	4,24%
10. Italy	3,25%	2,82%	3,08%	3,85%
11. South Korea	3,15%	3,91%	3,02%	2,50%
12. Netherlands	2,70%	2,76%	2,70%	2,63%
13. Norway	2,48%	2,88%	2,06%	2,50%
14. Ukraine	1,77%	1,54%	1,29%	2,50%
15. Switzerland	1,46%	1,79%	0,96%	1,61%
16. Hungary	1,28%	1,73%	1,16%	0,96%
<b>Σ</b>	<b>69,45%</b>	<b>72,86%</b>	<b>63,07%</b>	<b>70,3%</b>

Note: Sorted by the proportion of all the medals won in relation to all possible medals.

Source: IOC – own calculation of proportions

**Table A3 Variance covariance matrix of estimated results from model specification**

Frontier	Year	Year <sup>2</sup>	Ln(population)	Ln(real GDP per capita)	Ln(exports)	Constant
Year	1.0000					
Year <sup>2</sup>	-0.7243	1.0000				
Ln (population)	0.1570	-0.0005	1.0000			
Ln(Real GDP per capita)	-0.7063	0.3105	-0.4478	1.0000		
Ln(exports)	-0.2074	-0.2956	-0.0981	-0.0262	1.0000	
constant	0.5198	-0.1986	-0.5623	-0.4588	-0.1074	1.0000

Source: Own calculation of proportions

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