Forecasting National Medal Totals at the Summer Olympic Games Reconsidered

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Objective. This article aims at explaining national medal totals at the 1992–2016 Summer Olympic Games ($n = 1{,}289$ observations) and forecasting them in 2016 (based on 1992–2012 data) and 2020 with a set of variables similar to previous studies, as well as a regional (subcontinents) variable not tested previously in the literature in English. *Method.* Econometric testing not only resorts to a Tobit model as usual but also to a Hurdle model. *Results.* Most variables have a significant impact on national team medal totals; it appears to be negative for most regions other than North America except Western Europe and Oceania (not significant). Then, two models (Tobit and Hurdle) are implemented to forecast national medal totals at the 2016 and 2020 Summer Olympics. *Conclusion.* Both models are complementary for the 2016 forecast. The 2020 forecast is consistent with Olympic Medals Predictions, although some striking differences are found.

The 2020 Summer Olympic Games will take place in Tokyo. Consistent with what happens before each Olympics edition, predictions about the national team medal totals have been made, based on the latest observed sporting results (Olympic Medals Predictions, 2020). The problem with such predictions is that they do not inform about the socioeconomic, political, and sporting determinants explaining why such sporting results are supposed to come out. In the academic literature, a number of research works have attempted to explain medal win distribution at Summer Olympics with models that encapsulate the aforementioned types of variables. In a similar vein, this article aims at explaining previous national team medal totals at the 1992–2016 Summer Olympic Games ($n = 1{,}289$ observations) with a similar set of variables though including the test of a regional variable that has not been taken on board in the literature in English so far, although Andreff,

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Andreff, and Poupaux (2008) tested it in an article in French aiming at forecasting medal totals at the 2008 Beijing Olympics. Another objective is to work out econometric testing not only resorting to a Tobit model as usual but also to a Hurdle model. Two models (Tobit and Hurdle) are then implemented to forecast national team medal totals at the 2016 (based on the results from 1992 to 2012) and 2020 (based on the results from 1992 to 2016) Summer Olympics.

The article reads as follows. First, a literature review enables to identify potential explanatory variables; second, a new model, and its variants, is presented; third, the results of our explanatory models are exhibited for the 1992–2016 period; fourth, derived forecasting models are tested over the same period of time; fifth, forecasts for the 2016 Summer Olympic Games are provided; sixth, estimated forecasts for the 2020 Summer Olympic Games are exhibited and then compared with estimates published in Olympic Medals Predictions as of January 28, 2020. The last section concludes.

Literature Review

Explaining Summer Olympics medal win distribution and, consequently, national medal totals is not a brand new train of thought. This kind of exercise started as early as in the 1970s, though an important step forward was achieved in 2004. That year, Bernard and Busse (2004), comparing the different econometric methodologies, came up with the conclusion that a Tobit model always delivers better results. Then it became standard to estimate an explanatory model of medal wins distribution with a Tobit (e.g., Andreff, Andreff, and Poupaux, 2008; Forrest, Sanz, and Tena, 2010) and, since Bernard and Busse geared their article toward prediction as well, the Tobit regression turned out to be the hard-core methodology in forecasting national medal totals.

Bernard and Busse (2004), working with panel data on the 1960–1996 Summer Games, first estimated a model that explains a nation's share in the total number of medals. Probit and Tobit regressions were used. The hypothesis that medal winning should be proportional to population was econometrically rejected. Interestingly, per capita income and population were found to have very similar and significant effects at the margin on the production of Olympic medals. This suggests that total GDP is the best predictor of national Olympic performance. The model was then used to predict the number of medals won by Australia in 2000, and the result was only slightly different from the observed total. Bernard and Busse concluded that forced mobilization of resources by governments can also play a role in medal total—an argument that probably applies in retrospect to past Soviet and Eastern European Olympic performances too.

Fully in tune with Bernard and Busse, Andreff, Andreff, and Poupaux's (2008) modeling took on board GDP per capita, population, a host effect, and a political regime variable delineating more precise subsamples among the postcommunist economies than in Bernard and Busse's article. An additional regional variable was supposed to capture different sports specialization in different regions (subcontinents) of the world economy, namely, *NAM* (North America), *AFN* (North Africa), *AFS* (Sub-Saharan Africa), *LSA* (Latin and South America), *EAST* (Eastern Europe), *WEU* (Western Europe), *OCE* (Oceania), *MNE* (Middle East), and *ASI* (Asia). The dependent variable, in contrast with Bernard and Busse, was national medal totals rather than a country share (percentage) in the total medal distribution. It appeared that adding a variable standing for the number of medals won by each country at the previous Olympics (in $t - 4$ for the Olympics in t) markedly improved the censored Tobit econometric results, as already shown by Bernard and Busse; the underlying rationale is that, to a nonnegligible extent, past Olympic successes are predictors of current Olympic performances. This was a useful lesson for those running models with a view to forecasting forthcoming national medal totals. Note that GDP per capita and population are four years lagged (values taken in $t - 4$) with the underlying assumption that a given span of time is required to prepare an Olympic team, here assessed to be four years; put otherwise, as soon as the $t - 4$ Olympics are over, each national team starts preparing for the t Olympics. By the same token, some inertia is introduced this way into the model, which may avoid explosive variations when it is used for forecasting. Interestingly, compared to *WEU*, the regional variable unveils a significant positive impact for *AFS*, *NAM*, and *OCE*, no significant impact for *LSA*, and a significant negative impact for *AFN*, *ASI*, *EAST*, and *MNE*. Despite this variable being significant, it has not been used since Andreff, Andreff, and Poupaux (2008), maybe because this article is in French and, as such, not taken into account in the literature reviews conducted by authors focusing on papers in English.

Andreff, Andreff, and Poupaux (2008) published their article prior to the 2008 Beijing Olympics. Andreff (2009) compared their forecasts with actual medals, finding that Andreff, Andreff, and Poupaux (2008) predicted correctly 70 percent of the medals with a 95 percent confidence interval and even 88 percent with a two-medal error margin. Andreff (2009) identified doping as the explanation for those countries for which forecasts were not accurate.

Forrest, Sanz, and Tena (2010) adapted the Bernard and Busse model to include two new covariates, namely, the level of public expenditure on recreational, cultural, and religious affairs (including sport) in each country provided by the United Nations and whether future hosts of the Games have such a great incentive to raise their performance standards that this is already reflected in their achievements in the current Olympiad. Both variables have a significant positive impact on the shares of medals for the 1992–2004 Olympics. The authors then attempted to forecast national team medal totals at the 2008 Beijing Olympics. To do so, they made subjective, judgmental adjustments, for example, that the extra medals attributable to the old way of doing things for the postcommunist economies will fade away over time, which is confirmed "objectively" by Forrest et al. (2015, 2017) and Noland and Stahler (2016, 2017).

Vagenas and Vlachokyriakou (2012) looked at the predictors of medal totals at the 2004 Olympics. They tested two new variables, namely, the impact of having hosted the Games four years earlier and the number of participant athletes per country. For both variables, they found a significant positive impact. Also introducing a new variable, Vagenas and Palaiothodorou (2019) exhibited empirical evidence contrary to the hypothesis of climatic impact on Olympic performance, in particular no superiority of temperate climate nations shows up from a Tobit testing on six Summer Games (1996–2016). Leeds and Leeds (2012), Trivedi and Zimmer (2014), and Lowen, Deaner, and Schmitt (2016), looking at the impact of gender (for the first two) or gender inequalities (for the latter), did not find any significant result.

Blais-Morisset, Boucher, and Fortin (2017) attempted to explain a nation's medals total for the 1992–2012 Olympics. The chosen dependent variable is discrete, and drives the authors to estimate a Poisson model and then a negative binomial model, including a Zinb (zero-inflated negative binomial) model specification rather than a Tobit as in most previous studies. Similar to Forrest, Sanz, and Tena (2010), the authors tested the impact of the level of public expenditure on recreational, cultural, and religious affairs. They found that it is a better indicator of Olympic performances than GDP per capita. The authors interpret their result as public investment in sports being a better targeted governmental policy tool in view to gaining a nation's successes at the Olympics. Extremely topical and interesting, such result is to be taken with a pinch of salt due to a serious limitation. Indeed, it has been found with a sample of 53 nations, which is roughly one-quarter of all participating nations in the last Olympics.

Compared to the aforementioned studies, Celik and Gius (2014), studying the 1996–2008 Olympics, used a different dependent variable: instead of the number (or the share in total) of national medal totals at the end of the Games, they subtracted those medals stripped off from athletes ex post disqualified for doping. Otherwise, their model was basic, with population, GDP per capita, host effect, and the number of medals awarded at the previous Games, the latter improving the forecast of national medal totals once cleaned from disqualifications.

Otamendi and Doncel (2018) raised the issue of whether the medal win distribution is better anticipated by forecasting models or by sports experts who have a deep knowledge of the different Olympic sport disciplines. They compared five expert predictions published in the press with three forecasting models, respectively, used for the 2010 Vancouver Winter Olympics (Otamendi and Doncel, 2014a), the 2012 London Summer Olympics (Otamendi and Doncel, 2014b), and the 2014 Sochi Winter Games (Andreff, 2013). Relying on indicators to test the performance of a forecast such as a ratio of exactly predicted results, Pearson, Kendall, and Spearman correlations adjusting the forecast of ex ante statistical distribution to the ex post observed statistical distribution, the authors concluded that sports experts' predictions are more accurate as regards the detailed medal distribution within a given sport discipline while econometric models perform better when it comes to medal wins distribution across participating nations. Otamendi and Doncel's (2018) final comment suggests that expert forecasts are more to be used by sport punters, whereas econometric forecasts are more useful for designing public sport policies. The latter is the outlook of the modeling adopted below.

Data and Methodology

What is intended here is to compare from a forecasting perspective the results of estimating a Tobit and a Hurdle model, in a panel with random effects for both. Data have been gathered for all Games from Barcelona 1992 up to Rio de Janeiro 2016 ($n = 1{,}289$ observations).

Variables

First of all, the dependent variable $Mapdisq_{i,t}$ is, for nation i in year t, a corrected number of medal wins, which may not be equal to the actual number of medals won and publicized right after ending the Games. $Mapdisq_{i,t}$ is a national medals total *after* deducting all ex post medals lost due to (often doping) disqualifications of nation *i*'s athletes.[1] Data are from ⟨https://en.wikipedia.org/wiki/Summer_Olympic_Games⟩, the Summer Olympics Wikipedia English site that links to web pages of different Games where tables are found regarding medal totals, medallists' disqualifications, and medals' reallocations; references to IOC official data are reported so that double-checking can be done. It is worth noting that a better assessment and accounting of the doping impact on Olympic performances would

[1] Now, the World Anti-Doping Agency (WADA) and its national agencies can make anti-doping tests during 10 years after the Games. Consequently, the final actual outcome of the Games is definitively stabilized only in $t + 10$ (in 2026 as regards the 2016 Rio Games), and disqualifications may happen at any moment meanwhile.

require information about the number of all doped (including nondetected) athletes, which would enable to use doping as an explanatory variable instead of using it as an alleviation of the dependent variable. Such information has no chance to be unveiled in any foreseeable future (Andreff, 2019). Therefore, doping remains a nonobservable—and widely unobserved[2]—variable in view to explaining and forecasting national medal totals so far.

Turning now to other variables, six basic explanatory variables significant in Bernard and Busse (2004) and Andreff, Andreff, and Poupaux (2008) works are kept as our model's hard-core:

(1) $N_{i,t-4}$ stands for population in participating country i four years earlier than year t Olympics. Data are collected from the World Bank ⟨https://data.worldbank.org/indicator/SP.POP.TOTL⟩, and the variable logarithm is used in estimating our model variants.
(2) $(Y/N)_{i,t-4}$ stands for gross domestic product (GDP) per inhabitant in nation i four years earlier than year t Olympics and is assumed to capture the nation's level of economic development, differentiating rich/developed and poor/developing countries.

These first two variables are taken four years earlier under the assumption that nation i needs to mobilize economic and demographic resources four years in advance to prepare its Olympic team and have it ready for the year t Olympics. In the background, the rationale is that human and economic resources need to be available from the starting point of the national Olympic team's preparation for the next Games, which we assume to start up right after the end of previous Games, that is, four years earlier.

Data are constant purchasing power parity GDP, in 2011 million U.S. international dollars, and data are collected from the CEPII database called CHELEM open on the DBnomics site ⟨https://db.nomics.world/CEPII/CHELEM-GDP⟩, except for Puerto Rico (absent in the database). For the latter country, constant PPP GDP has been found in the World Bank database.

(3) $Host_{i,t}$ is a dummy variable supposed to capture a host country effect on medal wins and is equal to 1 for host countries and equal to 0 for other participating nations.
(4) $Political\ Regime_{p,i}$ is a dummy that differentiates among participating nations between former socialist centrally planned economies, that is, Central Eastern European countries (*CEEC*), which have joined the European Union, then all other (post)communist economies (*POSTCOM*), and capitalist market economies (*CAPME*), which all other countries in the world are assumed to be. However, in most recent studies (Forrest et al., 2015, 2017; Noland and Stahler, 2016, 2017) postcommunist transition economies did benefit much less from their outlier[3] situation than at the dawn of the transition period or before it, when Soviet-style sports were very much supported by the state to win medals. Consequently, the $Political\ Regime_{p,i}$ variable classifies all participating nations into three country groups:

[2] According to WADA published data, only between 0 and 1.9 percent of all tested athletes are found positive (doped), depending on which sport discipline they compete in.

[3] Communist countries were outliers in the following sense: for instance the GDR, the USSR, etc., were winning many more Olympic medals than noncommunist countries with comparable GDP per capita and population.

CEEC: Eleven postcommunist nations that joined the European Union (Bulgaria, Croatia, the Czech Republic,[4] Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia).

POSTCOM: Twenty-three other (post)communist nations that are not E.U. members (Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, China, Cuba, Georgia, Kazakhstan, Kosovo, Kyrgyzstan, Laos, Macedonia, Moldova, Mongolia, Montenegro, People's Republic of (North) Korea, Russia, Serbia,[5] Tajikistan, Ukraine Uzbekistan, and Vietnam).

CAPME: Capitalist market economies, without differentiation, assuming that all other participating nations are such economies; this country group is taken as the reference.

(5) $Regions_{r,i}$ is a dummy that classifies each nation i into one of the nine following country classes : *NAM* (North America), *AFN* (North Africa), *AFS* (Sub-Saharan Africa), *LSA* (Latin and South America), *EAST* (Eastern Europe), *WEU* (Western Europe), *OCE* (Oceania), *MNE* (Middle East), and *ASI* (Asia). Following up Andreff, Andreff, and Poupaux (2008), this variable is assumed to be a proxy for nations' cultural and regional specialization in some given sports disciplines, common to several countries in the same region in the world.[6]

(6) Medal totals four years earlier $M_{i,t-4}$ is the actual number of medals won by nation i at previous Games net of ex post disqualifications. This variable is taken on board to make our model ergodic and because it improves more than slightly medal win forecasts (Bernard and Busse, 2004; Celik and Gius, 2014); it is introduced only in forecasting variants of the model.

Beyond these six variables, three other variables have been tested to check whether their explanatory power makes it worth including them in our model: the number of participating athletes per national team; hosting the Games four years later; and having hosted the Games four years earlier.

(1) $NA_{i,t}$ stands for the number of participating athletes in each national team i, the rationale being that countries fielding more athletes are more likely to win medals. Data are drawn from the Wikipedia site ⟨https://en.wikipedia.org/wiki/2016_Summer_Olympics#Participating_National_Olympic_Committees⟩ for each Olympic Games from 1992 to 2016. It is first tested as a continuous variable. Then it is tested as a discrete variable $RNA_{i,d,t}$, which splits the number of participating athletes into four classes (from 0 to 9 athletes, from 10 to 49 athletes, from 50 to 149 athletes, and 150 athletes and over), for two reasons. For the one, from an analytical standpoint, a marginal return to the number of participating athletes may not be constant.

Making the variable discrete enables dropping a constant return assumption. On the other hand, such discrete variable enables having some information about the potential number of participating athletes that can be used when forecasting national medal totals at the next Games without knowing ex ante the exact number that each national team will actually field.

Note that athlete selection in the host country's Olympic team obeys specific criteria (lower sporting performance requirements) with an ensuing consequence that

[4] Czechoslovakia as regards data for 1992, before the split with Slovakia in 1993.

[5] Republic of Serbia-Montenegro from 1992 to 2006, before the split with Montenegro.

[6] As, for instance, sprint in North America, Jamaica, and the Caribbean, marathon and long-distance running in Ethiopia, Kenya, and Eastern Africa, weightlifting in Bulgaria, Turkey, Azerbaijan, Iran, etc.

a nation fields a bigger number of athletes when it hosts the Games than otherwise. Obviously, the two variables—host country and the number of participating athletes—are linked. Three different models are required to disentangle them, taking on board, respectively: (1) the host country effect alone (model 1 below); (2) only the number of participating athletes as a continuous variable (model 2 below); and (3) the two variables together while considering the four athlete classes—a discrete variable (model 3 below, used for forecasting).

(2) A second variable *Host in 4 years*$_{i,t}$ stands for the impact on a nation *i*'s Olympic performance of its knowledge that it will be hosting the next Games four years later. The underlying assumption is that being the next organizing host country, this nation's athletes will start up training and preparing themselves in advance with the objective of achieving very high level Olympic performances when they will benefit from the host effect. Usually, the Games are awarded to a city/country about seven years in advance ($t - 7$), thus an early preparation of the Olympic team may be beneficial in terms of medal wins as early as in the next Games in $t - 4$. Such effect was mentioned, for example, when explaining why the British team was so successful (47 medals) at the 2008 Beijing Olympics. Maennig and Wellbrock (2008) tested a so-called "Great Britain will host the 2012 Olympics" variable as significantly positive.

(3) The third and last variable, *Host 4 years ago*$_{i,t}$, stands for having hosted the Games four years earlier, the rationale being that the investment made in view to winning many medals during the Games hosted in t should still affect positively the host country's Olympic performance four years later in $t + 4$. The intuition is as follows: intensively preparing and training athletes to win more medals when a nation is hosting the Games in t may have lasting beneficial effects up to the next Games when the nation is no longer the host country. Thus, the *Host 4 years ago*$_{i,t}$ variable is equal to 1 for a nation i when it had been the previous Games-organizing country. For instance, taking Great Britain as an example, hosting the 2012 London Games translates in our models into *Host in 4 years*$_{i,t}$ $= 1$ for 2008, *Host* $= 1$ for 2012, and *Host 4 years ago*$_{i,t}$ $= 1$ for 2016.

Tobit and Hurdle Modeling

As mentioned previously, we have estimated both Tobit and Hurdle models. The use of a Tobit model is justified by the large mass points at zero medal (Bernard and Busse, 2004; Forrest et al., 2017). As noted by Forrest et al. (2017), the data are therefore treated as subject to censoring, which is intuitive because some countries come closer than others to winning a medal, for example, they win some fourth places, yet the performances of all of them are recorded as zero. In their article, these authors choose to use a Tobit model for three reasons. First, this facilitates comparison with Bernard and Busse (2004). Second, it is hard to think of theoretical reasons why the Tobit model would be inappropriate since it appeared to them plausible that the same mechanisms (resources) would drive both whether a country would win medals and how many it would win if it did. Third, their focus was to be on individual sports with comparisons across them based on medal shares rather than medal counts to control for the different numbers of medals available in each sport at each Games; therefore, a count model such as Poisson would make comparisons across sports not straightforward.

By contrast with Forrest et al. (2017), we are not interested in individual sports with comparisons across them and use medal counts. Therefore, we can also test a model that explicitly accounts for the discrete nature of the dependent variable, that is, the number of medals (Blais-Morisset, Boucher, and Fortin, 2017). As suggested by Blais-Morisset, Boucher, and Fortin (2017), a count model such as Poisson can be used. This is in particular possible when the dependent variable takes discrete values that are quite low, as this is the case for most countries regarding the number of medals won at the Olympic Games. Poisson models have the particularity to assume that the expected value and variance of the random variable are equal. Such a hypothesis is relatively constraining and not realistic in our case since there is a strong heterogeneity across countries. In order to account for this heterogeneity, a negative binomial model is considered, which generalizes the Poisson model by introducing in the expected value an unobserved individual effect. Given that the number of countries winning no medal is quite important, a Zinb model could have been chosen, consistent with Blais-Morisset, Boucher, and Fortin (2017). However, such model assumes that the zero observations have two different origins (Hu, Pavlicova, and Nunes, 2011): "structural" (e.g., a country does not take part in the Olympic Games) and "sampling" (e.g., a country takes part and scores zero medal at the Olympic Games). This model is not appropriate for our research since the focus is on countries having taken part in the Olympic Games.

Eventually, a Hurdle model is estimated. Contrary to the Zinb model, it does not assume that the zero observations have two different origins (Hu, Pavlicova, and Nunes, 2011). Similar to the Tobit model, the Hurdle model accounts for the probability of winning no medal and for the number of medals; its advantages compared to the Tobit model are that it distinguishes between two equations (medal(s) or not, then the number of medals for countries winning at least one medal, only the second equation being released later in the results) and explicitly accounts for the discrete nature and the asymmetric distribution of the dependent variable. It remains to observe whether this translates into forecasts that are more accurate. Thus, all regressions are estimated with both Tobit and Hurdle models, tested in a panel with random effects, in which $Mapdisq_{i,t}$ is the number of medals won by country i at the Games organized in t.

For the Tobit model, the general specification is:

$$Mapdisq^{*}_{i,t} = X_{i,t}\Theta + u_i + \epsilon_{i,t},$$

where $u_i \sim N\ (0,\sigma^2{}_u)$ and $\varepsilon_{i,t} \sim N\ (0,\sigma^2{}_\varepsilon)$, and $Mapdisq_{i,t}$

$$= \begin{cases} Mapdisq^{*}_{i,t} & \text{if } Mapdisq^{*}_{i,t} > 0 \\ 0 & \text{if } Mapdisq^{*}_{i,t} \leq 0. \end{cases}$$

For the Hurdle model, the general specification for the part related to the count process[7] is:

$$\chi_{i,t} = \exp\left(X_{i,t}\Theta + \tau_{i,t}u_i\right),$$

where $Mapdisq_{i,t} \sim \text{Poisson}(\chi_{i,t})$; $\chi_{i,t}|u_i \sim \text{Gamma}(\exp(g_{i,t}))$; $u_i \sim N(0, \sigma^2{}_u)$.

Depending on the set of explanatory variables selected, $X_{i,t}\Theta$ is defined by:

$$c + \alpha \ln N_{i,t-4} + \beta \ln\left(\frac{Y}{N}\right)_{t-4} + \gamma Host_{i,t} + \sum_{p} \delta_p PoliticalRegime_{p,i}$$

[7] The equation related to the probability (Probit model) of not winning one medal and the associated estimations are not reported in this article. The Probit part and the negative binomial model are assumed to be uncorrelated.

TABLE 1

Summary Descriptive Statistics

	Mean	*SD*	Minimum	Maximum
Number of medals	4.96	13.53	0	121
Population in millions (*t* – 4)	33.12	124.10	0.01	1,350.70
GDP per capita in K$ (*t* – 4)	14.84	17.70	0.07	125.65
Host country	0.01	0.07	0	1
Number of athletes	57.94	100.81	1	646
Political regime				
CAPME	0.83	0.38	0	1
CEEC	0.06	0.24	0	1
POSTCOM	0.11	0.32	0	1
Subcontinent				
North America	0.05	0.23	0	1
North Africa	0.03	0.16	0	1
Sub-Saharan Africa	0.25	0.43	0	1
Asia	0.15	0.35	0	1
Latin and South America	0.15	0.36	0	1
Eastern Europe	0.14	0.35	0	1
Western Europe	0.11	0.31	0	1
Middle East	0.08	0.27	0	1
Oceania	0.05	0.21	0	1

$$+\sum_{r}\rho_{r}Regions_{r,i} + \lambda Host\ in\ 4\ years_{i,t} + \mu Host\ 4\ years\ ago_{i,t} \qquad (1)$$

$$c + \alpha \ln N_{i,t-4} + \beta \ln\left(\frac{Y}{N}\right)_{t-4} + \sum_{p}\delta_{p}PoliticalRegime_{p,i} + \sum_{r}\rho_{r}Regions_{r,i} + \nu NA_{i,t}. \qquad (2)$$

It is worth noting that the number of participating athletes affects the impact of the three hosting variables, which lose statistical significance when taken on board together with the number of participating athletes. This explains why the three hosting variables are not included in Model (2). Table 1 presents summary descriptive statistics for the covariates included in the models ($n = 1{,}289$ observations).

Results of Explanatory Models

The results obtained with both Tobit and Hurdle models show that most variables have a significant impact on the medal totals (Table 2): the impact is positive for population and GDP per capita four years earlier, the two specific postcommunist political regimes, the usual host effect, hosting the Games four years later, having hosted the Games four years earlier, the number of participating athletes; it is negative for most regions other than North America except Western Europe and Oceania (not significant).

Results of Forecasting Models

The number of participating athletes cannot be directly used in forecasting models since the number of participants in each national Olympic squad is not known yet. However, the importance of this variable as a medal win determinant leads us to take it on board in forecasting models, though in a different manner: the variable is made discrete by means

TABLE 2

Estimation Results of Four Explanatory Models

	Model (1)—Hurdle		Model (1)—Tobit		Model (2)—Hurdle		Model (2)—Tobit	
	Coef	*SD*	Coef	*SD*	Coef	*SD*	Coef	*SD*
Constant	−9.481***	0.93	−125.377***	11.89	−6.108***	0.87	−62.923***	9.25
Population in log (t − 4)	0.558***	0.04	6.602***	0.59	0.364***	0.04	2.678***	0.43
GDP per capita in log (t − 4)	0.243***	0.06	3.456***	0.69	0.165***	0.05	2.156***	0.55
Host country in 4 years	0.359***	0.11	9.352***	2.16				
Host country t	0.519***	0.11	17.817***	2.16				
Host country 4 years ago	0.303***	0.10	11.104***	2.16				
Number of athletes/10					0.034***	0.00	1.101***	0.06
CEEC	1.134***	0.41	11.419	7.46	0.952***	0.31	5.644	4.47
POSTCOM	1.020***	0.33	14.298**	5.73	0.875***	0.25	10.349***	3.49
North Africa	−1.385***	0.41	−20.733***	6.80	−0.947***	0.33	−8.979**	4.32
Sub-Saharan Africa	−0.886***	0.33	−18.859***	4.73	−0.458*	0.27	−6.472**	3.05
Asia	−1.510***	0.30	−22.291***	5.02	−0.957***	0.24	−8.860***	3.09
Latin and South America	−1.169***	0.32	−16.422***	4.89	−0.872***	0.25	−7.899***	3.04
Eastern Europe	−0.926**	0.40	−15.448**	7.18	−0.678**	0.31	−8.800**	4.33
Western Europe	−0.047	0.28	−6.117	4.93	−0.024	0.22	−7.165**	3.03
Middle East	−1.335***	0.34	−20.464***	5.10	−0.839***	0.27	−−7.751**	3.30
Oceania	0.735	0.46	−4.859	6.86	0.390	0.35	−7.591*	4.52
$g_{i,t}$	−3.374***	0.24			−3.341***	0.24		
$\sigma^2{}_u$	0.350***	0.06	164.685***	23.67	0.355***	0.06	51.907***	8.36
Observations total	554		1,289		554		1,289	
Observations noncensored			554				554	

NOTE: ***Significant at the 1 percent level; **5 percent level; *10 percent level.; coef, coefficient; *SD*, standard deviation.

of grouping data into four classes corresponding to a number of athletes between 0 and 9, 10 and 49, 50 and 149, 150 and more. Although the number of participating athletes per nation is not known yet, its evolution across the different Olympics editions does not induce a change of class for any given country with the four above-defined classes; thus, a discrete variable for the number of participating athletes (noted RNA below) would fit with forecasting models. Compared to the above explanatory models, the two forecasting models encompass one more explanatory variable: the medal totals four years earlier.

$X_{i,t}\Theta$ is defined by:

$$c + \alpha \ln N_{i,t-4} + \beta \ln \left(\frac{Y}{N}\right)_{t-4} + \gamma Host_{i,t} \sum_{p} \delta_p Political\mathrm{Reg}ime_{p,i} + \sum_{r} \rho_r \mathrm{Reg}ions_{r,i}$$

$$+ \sum_{d} \iota_{nd} RNA_{i,d,t} + \theta Maqdisq_{i,t-4} + \lambda Host\ in\ 4\ years_{i,t} + \mu Host\ 4\ years\ ago_{i,t} \qquad (3)$$

TABLE 3

Estimation Results of Two Forecasting Models

	Model (3)—Hurdle		Model (3)—Tobit	
	Coef	*SD*	Coef	*SD*
Constant	−3.725***	0.92	−22.507***	4.57
Population in log (t – 4)	0.231***	0.04	0.700***	0.19
GDP per capita in log (t – 4)	0.067	0.05	0.569**	0.28
Host country in 4 years	0.336***	0.10	8.864***	2.02
Host country t	0.366***	0.11	12.520***	2.03
Host country 4 years ago	−0.050	0.11	−4.760**	2.08
Number of medals (t – 4)	0.016***	0.00	0.897***	0.02
Athletes [10,50[	0.510**	0.23	5.126***	0.67
Athletes [50,150[	0.989***	0.24	7.394***	0.87
150 athletes and more	1.559***	0.27	9.314***	1.15
CEEC	0.490*	0.27	0.390	1.40
POSTCOM	0.538**	0.22	1.828*	1.07
North Africa	−0.844***	0.28	−2.101*	1.29
Sub-Saharan Africa	−0.246	0.25	−1.749*	1.04
Asia	−0.618***	0.21	−1.719*	0.97
Latin and South America	−0.742***	0.22	−2.705***	0.96
Eastern Europe	−0.386	0.26	−1.890	1.35
Western Europe	−0.009	0.18	−1.205	0.90
Middle East	−0.520**	0.24	−1.373	1.07
Oceania	0.288	0.29	−1.772	1.39
$g_{i,t}$	−3.408***	0.25		
σ^2_u	0.115***	0.03	26.68***	1.66
Observations total	529		1,232	
Observations noncensored			529	

NOTE: ***Significant at the 1 percent level; **5 percent level; *10 percent level; coef, coefficient; *SD*, standard deviation.

The results show that medal totals four years earlier and the different participating athlete classes compared to the class from 0 to 9 athletes have a significant positive impact on medal totals, with an increasing coefficient for the participating athlete classes (Table 3). Compared to the explanatory models, GDP per capita and having hosted the Games four years earlier cease to be significant in the Hurdle model, while fewer political regime and region dummies are significant in the Tobit model. An explanation is that these four variables are correlated with the medal totals four years earlier, that is, the variable added in the forecasting models, with it capturing their impact. For GDP per capita, an additional explanation is that it mainly impacts whether a country wins medal(s) or not (rather than the number of medals for countries with at least one medal), that is, information provided by the equation not released for the Hurdle model.[8] In the Tobit model, having hosted the Games four years earlier has a significant negative impact. An explanation is that the medal totals four years earlier overestimate the medal total in t for the country having hosted the Games four years earlier. This overestimation is counterbalanced by the dummy variable capturing the fact that the country hosted the Games four years earlier, explaining its significant negative impact.

[8] Results for the first equation in the Hurdle model are available upon request.

TABLE 4

Forecast of Olympic Medals for the 2016 Rio Games

Countries	Number of Medals Rio 2016	Model (3)—Hurdle			Model (3)—Tobit		
		Forecast	Lower CI	Upper CI	Forecast	Lower CI	Upper CI
United States	121	**105**	94	115	**99**	95	102
China	70	**106**	95	117	**89**	86	93
Great Britain	67	**48**	43	53	**56**	51	61
Russia	55	**70**	63	77	**69**	66	71
France	42	**38**	34	42	**36**	34	38
Germany	42	**47**	42	51	**44**	42	46
Japan	41	**43**	38	48	**48**	43	53
Australia	29	**37**	31	43	**35**	31	38
Italy	28	**29**	25	33	**29**	28	31
Canada	22	**19**	15	23	**21**	19	24
South Korea	21	**29**	25	32	**31**	29	33
Brazil	19	**19**	15	23	**33**	28	38
Netherlands	19	**20**	17	23	**22**	20	23
Azerbaijan	18	**11**	8	13	**10**	8	13
Kazakhstan	18	**10**	8	13	**11**	9	13
New Zealand	18	**13**	9	17	**14**	10	17
Spain	17	**18**	15	22	**20**	18	22
Rate of right forecasts for 2016							
All countries (192)							
CI to 95% (+ or −2)		88.5% (93.2%)			83.9% (90.6%)		
Exact forecasts (+ or −1)		21.9% (77.1%)			43.2% (74.5%)		
Exact forecasts 0 medal (107 countries)		21.5%			69.2%		
Exact forecasts non-0 medal (85 countries)		22.4%			10.6%		
Countries with at least 3 medals (56)							
CI to 95% (+ or −2)		64.3% (76.8%)			50% (69.6%)		
Exact forecasts (+ or −1)		8.9% (37.5%)			8.9% (30.4%)		

NOTE: CI, confidence interval; forecasts in bold.

Forecasting National Medal Totals at the 2016 Rio Olympics

Running the two forecasting models based on the results obtained for the 1992–2012 period (not displayed in the article but available upon request) with the already known data pertaining to the 2016 Games, it appears that they perform well: they are able to predict between 82.3 percent (Tobit model) and 87.5 percent (Hurdle model) of overall medal wins with a 95 percent confidence interval (Table 4). Extending beyond the confidence interval by a two-medal error margin, between 91.1 percent (Tobit model) and 93.2 percent (Hurdle model) of the distributed medal totals are correctly predicted. The Hurdle model performs better than the Tobit model with a 95 percent confidence interval. Nevertheless, in a number of cases, its confidence interval is larger and leads to consider a forecast as accurate while this would not be the case with the confidence interval of the Tobit model. This is less frequently the case the other way round, meaning that the Hurdle model is more likely to present a better percentage independent of whether its exact forecasts are better than the Tobit model or not. To try to control for this issue, we calculated what would have been the rate of right forecasts for the Hurdle model with the 95 percent confidence

TABLE 5

Forecast of Olympic Medals for the 2020 Tokyo Games

	Number of Medals Rio 2016	Model (3)—Hurdle			Model (3)—Tobit		
Countries		Forecast	Lower CI	Upper CI	Forecast	Lower CI	Upper CI
United States	121	**139**	127	151	**115**	111	119
China	70	**77**	68	86	**70**	67	73
Great Britain	67	**57**	52	62	**64**	62	67
Russia	55	**55**	49	61	**55**	53	57
France	42	**59**	54	64	**51**	46	55
Germany	42	**45**	41	49	**42**	40	44
Japan	41	**47**	42	52	**53**	49	58
Australia	29	**33**	27	38	**29**	26	32
Italy	28	**29**	25	33	**29**	27	31
Canada	22	**20**	17	24	**25**	23	27
South Korea	21	**24**	21	28	**22**	20	24
Brazil	19	**13**	9	16	**15**	10	20
Netherlands	19	**20**	17	23	**20**	19	22
Azerbaijan	18	**12**	10	15	**18**	16	20
Kazakhstan	18	**12**	9	15	**18**	16	20
New Zealand	18	**14**	10	18	**18**	15	21
Spain	17	**18**	15	21	**19**	17	21
Denmark	15	**9**	7	11	**14**	12	16
Hungary	15	**17**	14	20	**16**	14	18
Kenya	13	**12**	10	15	**12**	10	14
Uzbekistan	13	**8**	5	10	**14**	12	15
Cuba	11	**13**	10	17	**14**	11	17
Jamaica	11	**10**	7	12	**10**	8	13
Poland	11	**14**	10	17	**13**	11	15
Sweden	11	**13**	10	15	**13**	11	15
Ukraine	11	**16**	13	20	**14**	12	16

NOTE: CI, confidence interval; forecasts in bold.

interval of the Tobit model. Interestingly, the results of the Hurdle model remain better than the Tobit model (87.0 percent of the distributed medal totals correctly predicted with a 95 percent confidence interval, 92.2 percent when the confidence interval is extended by a two-medal error margin). Given that the latter is the standard forecasting model since Bernard and Busse (2004) and a Hurdle model has never been tested to forecast national medal totals at Olympic Games, finding that the Hurdle model performs better with a 95 percent confidence interval is an important contribution to the forecasting literature.

With a view to optimize forecasts, it is worth investigating further the differences between the Hurdle and the Tobit models, as well as what works better with one model or the other. If the Hurdle model performs better with a 95 percent confidence interval, this is not the case for the rate of exact forecasts. Indeed, the Hurdle model forecasts correctly 21.9 percent of the numbers of medals versus 43.2 percent for the Tobit model. More exactly, the Tobit model performs better when it comes to forecasting which countries end with zero medal (69.2 percent vs. 21.5 percent for the Hurdle model), while the Hurdle model performs better when it comes to forecasting which countries end with one medal and more (22.4 percent vs. 10.6 percent, including the host country Brazil for the Hurdle model). These elements highlight that both models are complementary.

Forecasting National Medal Totals at the 2020 Tokyo Olympics

Now when forecasting models are run for the 2020 Games they come out with the predictions shown in Table 5. First, it is worth noting that our models forecast exactly the same set of top 13 countries as the one found in Olympic Medals Predictions (2020). Nevertheless, the respective country rankings and the number of medals reveal some differences. Both forecasts converge on the United States ending first with a large margin and China ending second. The most striking differences between modeled forecasts and Olympic Medals Predictions show up for Russia (−16 medals in models) and France (+19 to +27).

Medal totals for France heavily depend on whether the variables having hosted the Games four years earlier and hosting the Games four years later (since France is going to host the Games in 2024) are taken on board or not. When they are removed from the models, the forecast for France is 42 or 43 medals, that is, a lower medal total than for Japan and Germany. A key factor determining the medal total for France in 2020 would be whether preparing an Olympic team for 2024 had been engaged in as soon as in 2017, that is, when Paris was awarded hosting the 2024 Games, and whether such preparation would have a positive impact as early as in 2020.

Conclusion

This article aimed at explaining the previous national team medal totals at the 1992–2016 Summer Olympic Games ($n = 1{,}289$ observations) with a set of variables similar to previous studies, though including the test of a (significant) regional variable that was not taken on board in the literature in English so far. Another objective was to work out econometric testing not only resorting to a Tobit model as usual but also to a Hurdle model. Two explanatory models were then implemented to forecast national team medal totals at the 2016 and 2020 Summer Olympics. Forecasting national team medal totals at the 2016 Summer Olympics shows that the Hurdle model performs better than the Tobit model with a 95 percent confidence interval, questioning the relevance of using (only) the latter that became standard since Bernard and Busse (2004) and, as such, making an important contribution to the literature. Forecasting national team medal totals at the 2020 Summer Olympics provides results that are consistent with Olympic Medals Predictions (2020), although some striking differences are found.

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