

Fastest in the Pool: The Role of Technological Innovation on Swimming Record Breaks

E. Claire Preston and Daniel K. N. Johnson

Abstract—The ultimate goal of any world-class swimmer is to break a record, and technology enables that accomplishment. Using 40 years of data at the individual, national and international level, we identify the quantitative impact that innovation has had on the number of record breaks. We find small but statistically significant impacts on both the number of breaks and the interval between breaks.

Index Terms—Innovation, negative binomial, Poisson, record, sports, swimming, technology.

I. INTRODUCTION

During the Beijing 2008 Olympic Games, swimmers broke twenty-five world records and sixty-six Olympic records, leaving only a single previous Olympic record surviving [1]. While some of that success is clearly due to amazing athletic talent, the goal of this paper is to identify and measure the role that technological innovation has had in speeding up the elite swimmer, and therefore the rate of swimming record breaks.

Many studies have analyzed athletic performance in its most competitive form, most concluding that the development of superior physical performance is in part a result of technological innovation. Although many factors contribute to success in sports, technology (due to its potentially unfair advantage to swimmers from higher-income nations), appears to be the most controversial as it questions the legitimacy of performance times. Entire industries devote their business to the development of sport equipment, while national governments and international corporations annually invest billions in order to sustain public interest in recreation and health [2]. As an indicator of optimization, record breaks reflect the rate of change in athletic performance, so this study specifically focuses on the effects of improvements in swimming technology on world and American records broken from 1969-2009.

While swimming technology includes body techniques, much attention has been drawn to innovations in sport equipment including performance-enhancing machines and the evolution of competitive swimsuits [3]. It is undeniable that a huge technical jump occurred with the introduction of the first bodysuit, the Adidas JetConcept, which adapted commercial aircraft technology to reduce pool drag and influence how water flows around the swimmer's body. The media has both extolled and criticized the suits' extraordinary

light weight, the welded seams, and even the fabric which attempts to mimic the skin of a shark and the shape of a jet, molding the swimmers body into a more streamlined shape [4]. Speedo's follow-on innovation, known as Fastskin technology, led to thirteen out of fifteen world records broken that same year at the Sydney 2000 Olympics, where swimmers donning the new suit won eighty-three percent of all medals [5].

Facilities and equipment have changed remarkably as well. Deeper pools are designed to help absorb wave motion [5]. Olympic pools are now ten lanes wide for eight swimmers in order to have the outside lanes serve as buffers to keep waves from reverberating. Plastic lane divider buoys redirect water downward instead of outward, and non-skid starting blocks permit faster take-off. Video analysis monitors stroke counts, distance per stroke, split times, and the biomechanics of takeoffs. Critics argue about how these technical innovations create an inappropriate advantage for swimmers. This paper aims to impute the quantitative size of that advantage.

II. LITERATURE

Past research has shown that the demographic and economic characteristics of a country have significant explanatory powers for their athletes' abilities to prosper in athletic competition. Ball introduced the usage of economic models to determine athletic success [6], and most subsequent studies [7]-[9] recognize GDP and income per capita as the best predictors of athletic performance because they measure the resources available to athletes regarding health benefits, training, sponsorships, and infrastructure.

The population of a nation also contributes to athletic success since a larger population size increases the talent pool [7], [8], [10]. Estimates of how income per capita affects participation [8] conclude that it costs an average of \$260 in GDP per capita to send an athlete to the games. Richer countries therefore have more success in sports as they are able to involve more athletes in competition.

Athletic success also depends on the geography of the athlete's nation. Many studies show that colder nations perform better, whether measured by the average number of frost days per winter month [8] or the average latitude of the nation [11].

The host nation advantage is well-documented [7], [8] as a strong factor affecting the outcome of athlete performance. Most studies agree it may increase familiarity with infrastructure, influence biased referee calls while also increasing participation and morale with reduced travel costs and more audience support. Other factors analyzed in the literature include political systems [8], previous athletic

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success [7], importance and availability of an event to society [10], government expenditure [9], the presence of doping [12], and accurate timing protocols [13].

Some studies focus specifically on the role of specific technologic advances in determining success, on the positive impact that technical innovations like the klapskate have on speed skating world records [11], or on how technology maintains the frequency of record breaks in track and field [13]. Of the improvement in Olympic cycling times over 111 years, 45% is accountable to technological improvements [14].

With respect to swimming in particular, additional enhancement has improved the performance times of athletes by approximately 0.4% [15]. Bodysuits worn by competitive swimmers improved performance by 1.6% in controlled trials in the 50m crawl race [16].

III. DATA AND METHODOLOGY

Data on every one of the 736 individual record breaks over the period 1969-2009 were compiled [17], [18] to document athlete name, nationality, event, gender, performance time, location and date of the break. We also consider the data in aggregated form, summarized into the total number of breaks by year globally (41 observations) and as record counts for the 25 nations to break a swimming record during this period (1025 observations).

Natural-born athletes tend to break many records, often resulting in repeated sport success to specific swimmers. Mark Spitz, Kornelia Ender, and Michael Phelps are partly responsible for the high record breaks in 1972, 1976 and 2009, respectively, so in order to reflect the presence of those athletes, we define a “star athlete” variable which indicates the presence of any athlete that has broken at least three records in any event or year.

As shown in Table I, nearly thirty records are broken internationally in an average year, but of course, the standard deviation is high and breaks tend to cluster at international competitions, so the average duration between breaks is 20 days.

TABLE I: SUMMARY STATISTICS

Variable	Obs	Mean	St Dev	Min:Max
Records per year	41	29.51	19.91	3:84
U.S. records per year	41	11.56	8.56	1:39
Day lapse between records	735	20.24	49.13	0:342
GDP per capita (\$000s)	736	25.03	13.68	28.6:52.2
Latitude (degrees)	736	42.51	9.04	11.83:63.4 5
Innovations	736	1.11	1.55	0:5

GDP per capita was calculated for the home nation of each record-breaking athlete [19], [20]. Notice that the high average GDP per capita reflects the fact that poor nations rarely produce record-breaking swimmers, so our results will not be representative of all potential swimmers but only of those who broke a documented record.

Average latitudes for each record-breaking nation were collected [8] and confirmed [21]. Record-breaking swimmers live in colder climates as reflected by the prominence of the

USA (288 records), Germany (154 records), and Australia (103 records) as record-breaking nations. Of course, athletes may not reside at the specified latitude, depending on the size of the country. Again, due to the exclusion of all other competing nations, the estimated impact of latitude will only be accurate within-sample, as we do not have a random collection of participant nations among record-break data.

Logically, there are many factors this study could consider given more data. This includes the number of official meets offered each year, popularity of the sport, government expenditure on sports (and swimming in particular), individual and team sponsorships, doping regulations, and advances in sports nutrition. We trust that these omitted variables do not bias our results, but have no way to ascertain the impact of their exclusion, given the challenges in quantifying them.

We focus our technological attention on changes in swimsuits and fabrics, including other equipment or facility changes as a control to ensure that we do not inadvertently bias the results of our study. On average, one technology is introduced for every record broken that year, which makes the introduction of five technologies in one year a rare occurrence.

This study focuses on technology as the primary variable of interest, because given the levels of other factors, it should become increasingly difficult for records to be broken in the absence of rare talent or improvement in the elite athlete to improve beyond the level of previous elite athletes. In order to define innovations, we have compiled information on the introduction of a new swimsuit, fabric, or other major relevant innovation since 1969. However, there are serious limitations to our list. First, the value of each technological innovation is impossible to determine objectively without experimental protocols [16]. Hence, we are estimating the impact of the average innovation, where the range of improvement might be sizeable. Second, there are potentially omitted innovations that are kept confidential. Third, we implicitly assume that every technology introduced is available to every potential record-breaking athlete, which may not be the case.

A chronology of the major introductions of swimsuits, fabrics and other significant changes is displayed in Table II. In order to determine the number of swimming technologies introduced every year, information on the release of competitive swimsuits and fabrics were provided by the top swimming company websites such as Speedo, Arena, Nike, Jaked, TYR, and Adidas. Follow-up questions were asked via phone calls with those companies. If a new fabric introduced was designed for a specific swimsuit, then both technologies only count once in the total technology column. Furthermore, the table includes the Beijing Water Cube in 2008 due to the abundant records breaks broken in this specific pool. The pool’s significance lies in its increased depth and wider lane lines relative to all other pools because it alleviates the reverberations hindering a swimmer’s pace [5].

Table II also includes other key innovative technological moments [5], [22]-[25]. While we are reticent to define technique changes, when FINA publically approved the dolphin kick in competitive swimming (2005), we deemed it necessary to make an exception and include it within the data due to its open release [26]. We also must consider the

introduction of the starting block in 2007 as it has proven to shave seconds off of a swimmers race [17]. Accurate timing increases the frequency of records because the smaller the unit of reporting, the smaller the margin by which a record must be broken to be recognized especially in short distance events. Finally, the data set includes the introduction of the body suit concept, as the idea itself sparked a flood of new innovations.

TABLE II: CHRONOLOGY OF SWIMSUIT INNOVATIONS, 1969-2009

Year	Swimsuit	Fabrics	Other	Innov. count
1972	-	Speedo: nylon/elastine	-	1
1973	Arena Skinfit	-	-	1
1975	-	Speedo: lycra	-	1
1979	Arena Flyback	-	-	1
1990	Arena Aqua Racer	-	-	1
1993	-	Speedo: S2000	-	1
1994	Speedo Endurance	Speedo: 4-Way Stretch	-	1
1996	-	Aquablade	-	1
1997	Arena Xflat	-	-	1
1998	-	-	Adidas: body suit	1
2000	Speedo Fastskin, Diana Submarine, Nike Lift, TYR Aquapel, Arena Powerskin	-	-	5
2001	-	Speedo: FS	-	1
2003	Adidas Jet Concept, TYR Aquashift, Nike Swift	-	-	3
2004	XD Skin, Arena Powerskin Xtreme, Speedo FastskinII, Arena Powerskin X-treme	Speedo: FSII	-	4
2005	TYR Fusion	-	FINA allows dolphin kick	2
2006	Speedo Fastskin Pro	-	-	1
2007	-	Speedo: FSPRO	FINA allows Omega starting block	2
2008	TYR Tracer Light, TYR Tracer Rise, Speedo LZR Racer	Speedo: LZR Racer Pulse Polyurethane	Beijing Water Cube pool 3 meters deeper	4
2009	Arena Powerskin X-Glide, Jaked 01, Adidas HydroFoil, Arena Powerskin R-Evolution	-	-	4

We consider the sea access of a nation (presence of a coastline) as a proxy for the popularity of swimming within the nation, but this offers little differentiation within our

sample as only five sample countries are completely land-locked: Hungary, Poland, Serbia, Switzerland, and Zimbabwe.

IV. RESULTS AND ANALYSIS

Given these data and the previous literature, we propose a simple negative binomial multivariate regression to explain the number of record breaks in any given year, effectively modeling count data. We estimate a Poisson multivariate regression of the time between record breaks, to model interval spacing. In the absence of any structural model for this question, we propose a reduced form as:

$$Breaks = \beta_0 + \beta_1 Innovation + \beta_2 Latitude + \beta_3 Stars + \beta_4 GDPpc + \beta_5 SeaAccess + \beta_6 Host + \beta_7 Year + u \tag{1}$$

$$Duration = \beta_0 + \beta_1 Innovation + \beta_2 Latitude + \beta_3 Stars + \beta_4 GDPpc + \beta_5 SeaAccess + \beta_6 Host + \beta_7 Year + u \tag{2}$$

where

- Breaks* is the number of record breaks in a year;
- Duration* is the number of days between record breaks;
- Innovation* is the number of innovations in a year;
- Latitude* is the average latitude of the record-breaking athlete;
- Stars* is the number of athletic stars in a nation in a year;
- GDPpc* is the Gross Domestic Product per capita of the nation in a year;
- SeaAccess* is an indicator of whether the nation has a coastline;
- Host* is an indicator of whether the nation is the host of the record-breaking event;
- Year* is a time trend; and
- u* is the unexplained residual of the equation.

Primary results of estimated equations (1) and (2) are presented in Table III below. The first three columns model the number of record breaks using a negative binomial distribution, while the remaining two columns model the interval between breaks using a Poisson distribution. Our results have been corrected for heteroskedasticity using White-corrected standard errors, and have been suitably tested for multicollinearity and autocorrelation (neither of which is a problem here). We test for the presence of autocorrelation using the Durbin-Watson test, but find no cause for alarm once a time trend is included in the analysis. The results show equation-wide significance in every case.

Notice first that in every specification, innovation shows up statistically significant with the expected coefficient sign: adding to the number of record breaks, and reducing the interval between record breaks. Innovations appear to contribute an average of roughly 1/3 of a record break per year (a little more for Americans in particular, and an average of 1/6 of a record break per year for the average nation).

From another perspective, innovation reduces the time between breaks by an average of 0.12 to 0.08 days depending on whether individual or national data are used for the analysis. In other words, the estimated effect of technology is statistically significant, although fairly small in marginal

impact.

The coefficients on control variables show up largely as expected. Latitude is only occasionally significant, showing a reduction in the interval between breaks for more Northern athletes. Star athletes strongly increase the number of breaks and reduce the interval between breaks, swamping the size of all other variables in the analysis. Sea access has no significant effect on duration, but appears to speed up record breaks at the national level of analysis. Interestingly, while there is a significant constant rate to the continuous breaking of records in every specification (an interesting effect in itself, suggesting that some athletic improvement is perhaps

exogenous), that rate has been decreasing with time once innovation is accommodated (reflecting the fact that breaks become increasingly difficult with the passage of time).

There are a few paradoxes in the results as presented as well. For example, GDP per capita has no significant effect in most specifications, and oddly has a tiny effect to extend the duration between records at the national level. Perhaps this is due to the fact that star athletes frequently hail from (or immigrate to) nations with high GDP per capita. However, the correlation between those two variables is not exceedingly high, at only 0.20.

TABLE III: PRIMARY REGRESSION RESULTS

	Number of Annual Record Breaks - Global		Number of Annual Record Breaks - American		Number of Annual Record Breaks – Each nation in global competition		Interval between Record Breaks - Individual		Interval between Record Breaks – National	
Innovation	0.345	(4.52)***	0.396	(4.83)***	0.164	(3.22)** *	-0.120	(2.09)**	-0.081	(5.98)***
Latitude	---		---		7.99×10-3	(0.13)	-0.023	(2.06)**	-0.003	(0.95)
Stars	---		---		1.56	(11.5)** *	0.094	(0.49)	-0.190	(6.21)***
GDP per capita	---		---		2.23×10-6	(0.35)	-2.24×10-6	(0.25)	6.65×10-6	(2.49)**
Sea Access	---		---		0.901	(3.59)** *	-0.115	(0.22)	0.013	(0.11)
Host nation	---		---		---		0.623	(3.28)***	---	
Year	-0.033	(4.73)***	-0.033	(4.03)***	---		---		---	
Constant	68.124	(4.95)***	67.266	(3.29)***	-2.719	(8.32)***	3.811	(5.55)***	3.610	(30.06)***
Wald Chi2	(28.76)***		(25.13)***		(205.39)***		(20.04)***		(80.11)***	
Observations	41		41		1025		735		1025	

*** INDICATES SIGNIFICANCE AT THE 99% LEVEL, ** INDICATES SIGNIFICANCE AT THE 95% LEVEL, AND * INDICATES SIGNIFICANCE AT THE 90% LEVEL.

The host nation effect slows down record breaks as well, an effect which refutes the evidence of previous literature on other types of sporting events. This is not due to the fact that host nations are frequently home to star athletes (correlation 0.02), but remains to be explained by future scholarship.

V. CONCLUSIONS AND EXTENSIONS

As swimming technology continues to improve, swimming records should keep falling. The bulk of that phenomenon is due to factors outside of our model, showing that technology plays a demonstrably small role, at least as measured here. Whereas an average of 30 records fall every year, each technological innovation can only be held accountable for 1/3 of one record break per year. In addition, if a record break makes the news on average every 20 days, marginal technological change is only responsible for reducing that interval by a tenth of a day.

This does not imply that technology is unimportant, as the cumulative impact can be quite large despite the relatively small marginal effects. The fact that innovation, even measured as crudely as we must, has a measurable impact that is statistically identifiable in every specification presented, is quite surprising.

There are obvious limitations to our study, including the manner in which we identify and measure innovations. For example, to test the robustness of these results, we also

attempted to examine the time improvement of each record break as a separate dependent variable, both in absolute terms and as a percentage of the initial record. Our innovation variable was ineffective in all attempts, perhaps because this explanatory variable measures only the existence of an innovation rather than its value in seconds shaved from a record time.

Given the demonstrable impact on record breaks, it will be interesting to see how innovations are regulated within competitions. The sporting world must balance its dual obligations of providing the highest performance possible for the world to enjoy while also preserving the purity of the sport for the sake of its main intentions. Record breaks represent the ultimate success in athletics as they continue to shatter barriers deemed impossible by society. Record breaks create a dynamic interaction among fans, athletes, and media in order to maintain the thrill of a sport. While those record breaks are clearly determined by athletes (and especially star athletes), technological innovation has a small but identifiable role as well.

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