Technical Progress, Globalization, and Speed of Change: What Track and Field Records Show*

Lalith Munasinghe
Department of Economics
Barnard College, Columbia University

Brendan O'Flaherty
Department of Economics and
School of International and Public Affairs
Columbia University
Broadway Ultra Society and WSSAC

Stephan Danninger
International Monetary Fund

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Abstract

The past century and a quarter has seen frequent improvements in track and field records. We attempt to estimate what proportion of the speed of record breaking is due to globalization (competitors from more countries) and what proportion is due to technological progress (better equipment and training techniques). It appears that technological change is the chief driving force, but that technological progress is improving the performance of seasoned elite athletes faster than it is improving the performance of adolescents. Both our results and our methods may have wider application.

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1 Introduction

In the past century and a quarter, track and field has evolved markedly along two different dimensions: the technological and the geographic. In the late 1870s, only a handful of white men on the eastern seaboard of the United States and a few cities in western Europe participated in organized track and field events; they used haphazard equipment, trained sporadically, and most of what they believed about sports physiology was wrong. Today, track and field competition is a worldwide endeavor with many top competitors drawn from countries (like Kenya and Jamaica) that play far from a major role in either other sports or world trade; equipment is sophisticated, training is a full-time job for top competitors, and all of the latest results from the science of sports physiology see almost immediate application.

It is plausible that both technological change and globalization have contributed to improving track and field records over this period. The primary purpose of this paper is to try to assess the relative contribution of each; a secondary purpose is to try to find out whether the underlying improvement processes that are driving record-breaking are speeding up or slowing down.

To do this, we examine five different record progressions: world records, Olympic Games records, Millrose Games records, US records, and New Jersey high school records (we also use some fragmentary data on New York City public high schools). The basic idea is that the progress of records (like world and Olympic records) that can be set by anyone in the world should reflect both globalization and technological change, but the progress of records (like US. and N.J. high school records) that can be set (by definition) by only a geographically restricted set of people should reflect only technological change. Thus the difference between the rates of progress of the two types of records should give us an estimate of globalization.

To summarize our results: The processes driving world and Olympic records are improving only about 10% faster than the processes driving US. records, and so the comparison with US. records suggests that globalization is of little importance. Technological change appears to be the chief reason why track and field records are getting broken as quickly as they are. We find no evidence that the processes driving record-breaking are speeding up, and no evidence of any great slowing down, either.

This conclusion needs to be tempered, however, by our results on New Jersey high school records. These records are improving much more slowly than US. records. If we use the world-New Jersey difference as our estimate of globalization instead of the world-US. difference, then our conclusion is reversed: globalization accounts for over half of the improvement in records.

There is reason to believe, though, that the world-US. difference is the correct one to consider. N.J. high school records are set by adolescents with only a few years' experience in track and full-time school responsibilities. By contrast, it is adults with many years of experience and with few other responsibilities who set both US. and world records. What the gap between US. and New Jersey may be telling us then, is that technological change has been biased. As far as records go, things like high-altitude training, daily massages, and years of sharpening matter a lot more than all-weather tracks and Nike footwear. This is only speculation at this point, but it is testable.

In the rest of the paper we begin with theory. Section 2 discusses the theory of records and shows how globalization and technological progress could reduce the life span of records. In this discussion we will be careful to distinguish between rates of change and levels. For instance, the rate at which records are being broken does not depend on the level that technology has achieved; it depends only on the speed with which it is progressing. This distinction is usefully made in discussions of technical progress by Bartel and Sicherman (1998) and Jovanovic and Nyarko (1995). The rate of record breaking, moreover, is independent of the shape of the distribution from which individual performances are drawn and is not necessarily equal to the rate at which average performance is changing.

Section 3 is empirical: using records from track and field, we try to measure the speed of change, and account for its determinants. We use five different data sets, and explore a variety of different techniques. Section 4 concludes with a discussion of the possible relevance of our methods and techniques beyond track and field in areas of more traditional concern among economists. Much discussion of rising inequality and job instability in the US. has focussed on globalization and technological change, and so our study may shed light on these controversies. The methods we use, too, may have wider applicability, since records are statistics of optimization and so of natural interest to economists.

2 Records and the Speed of Change

2.1 Standard Results

Let $\{x_t\}$ denote a sequence of independent random variables drawn from a common continuous distribution function $F(.)$. We call V_1 the first lower record time and define by convention $V_1 = 1$. The first value observed is always a record. We call V_r the r-th lower record time; it is the time at which the n-th record is set. We define it inductively:

$$V_r = \min\{t : t > V_{r-1}, x_t < x_{V_{r-1}}\}$$

Finally we define Δ_r as the r-th lower inter-record time,

$$\Delta_r = V_r - V_{r-1}, \quad r > 2,$$

and e_t as the period t lower record indicator – a random variable that takes the value 1 if and only if a record is broken in period t:

$$e_t = 1 \ \text{ if for some } r,\ V_r = t, \text{ and } e_t = 0, \quad \text{otherwise.}$$

The statistics literature contains several helpful results about record processes. For easy reference, we will name them after their authors, although this is not the practice in statistics. The most basic is

Chandler's Result: *The distribution of the lower record times (V_r) – and hence of the (Δ_r) and (e_t) – does not depend on the underlying distribution $F(.)$ of the observations.*

The intuition behind Chandler's Result is simple. For any two periods s and t, $x_s < x_t$ if and only if $F(x_s) < F(x_t)$. Thus the sequence $(F(x_t))$ has the same lower record times as the sequence (x_t). But $(F(x_t))$ is a sequence of independent variables drawn from a uniform distribution on the unit interval. So any sequence, no matter what distribution it is drawn from, has the same distribution of lower record times as any other sequence – that is, the distribution of lower record times of a sequence drawn from a uniform distribution on the unit interval.

Chandler's Result has three immediate consequences. The first is terminological: it does not matter whether we talk about lower records or upper records (realizations that are maxima). Henceforth therefore we will talk simply of "records" without appending the designation of lower and upper.

The second consequence is that volatility does not depend on the level of technology. Since the distribution of record times does not depend on anything about $F(.)$ (except continuity), it does not depend on the mean value of x. Years between record low temperatures in Bombay are distributed just like years between record low temperatures (and record high temperatures) in New York. *Ceteris Paribus*, turnover of advanced technologies should be no more rapid than turnover of rudimentary technologies. Nor does the variance of the underlying distribution matter. Closeness of numerous competitors and "thinness" of competitive advantage by themselves have no impact on volatility.

The third consequence is that the prevailing technology need not have only a single challenger every period – as long as it has the same number every period. Suppose precisely 100 technologies challenge every period. Then $F(.)$ is simply the distribution of the minimum of 100 technologies; the distribution of record times is the same as it would be if there were only one challenger every period, since $F(.)$ does not matter.

Chandler's Result points up how important the assumption that the x_t are all drawn from the same distribution is. We call this the i.i.d. assumption. Since the phenomena we are ultimately interested in – globalization and technological change – do not conform to the i.i.d. assumption, we will ultimately have to drop it. But most published results rely on the i.i.d. assumption, and when we drop it we will do so in a manner calculated to preserve as many of these results as possible.

The next result is about record indicators.

Renyi's Result: *The record indicators* $e_2, e_3, ..,$ *are independent Bernoulli variables with* $Prob(e_t = 1) = \frac{1}{t}$.

Again the intuition is obvious. A record is broken at time t if and only if x_t is the minimum of the first t realizations in the sequence. Consider a set of t i.i.d. variables. The probability that any particular one of them, say the k-th, is the minimum is the same as the probability that any other is the minimum. So the probability that the k-th element in the sequence is the minimum is $(\frac{1}{t})$. So the probability that x_t is the minimum and hence the probability that $e_t = 1$ is $(\frac{1}{t})$. The argument for independence takes slightly more work and so we omit it.

The immediate consequence of Renyi's Result is that as time passes record breaks become more unlikely. Records get better and so are less likely to be broken. As elapsed time goes to infinity, record breaks become infinitely rare. Time itself is a force that diminishes volatility, and when we look at empirical data we will have to correct for the passage of time. A record low temperature is as likely in Bombay this year as it is in New York if both cities have been collecting weather data for the same length of time, but if Bombay's time series is longer, New York is more likely to break a record this year.

An immediate economic application is that new areas of endeavor change more quickly than old ones. Better techniques for making computer chips will be found more frequently these days than better techniques for making chairs.

Inter-record times have the same sort of properties as record indicators, as might be expected. It can be shown that

$$\text{Prob}(\Delta_r < v) = \int_0^\infty \{\frac{x^{r-1}}{(r-1)}\} exp(-x)(1 - exp(-x))^v dx,$$

where $r \geq 1$, and $v \geq 1$, and $\text{Prob}(\Delta_r = v)$ is decreasing in v for every r, but the expected value of Δ_r is infinite. Records are most likely to be broken immediately after they are set, but very long reigns are also possible. In the trade context this means that one region may dominate a particular activity for a very long time, but rapid turnover is also likely. As r increases, short reigns become less probable and long reigns become more probable.

For large r – records that have been broken many times – we have Neuts' Result: *as r grows infinitely large, the distribution of*

$$Z(r) = (ln\Delta_r - r)/\sqrt{r}$$

approaches the standard normal distribution.

For r fairly large, Neuts' Result is a quick way to correct for the passage of time. However for the data we use in this paper, we do not have enough record breaks to use this approximation.

2.2 Incorporating Change

These well-known results require the i.i.d. assumption, and so to apply them, we must carefully relax this assumption.

Globalization is easiest to understand. The way to think about globalization is as an increase in the number of challengers per period. We already remarked that because of Chandler's result the standard formulas still hold if there are a large number of challengers per period as long as that number is constant; the speed of change depends on the increase in the number of challengers not on its level. Fortunately, an increasing (or decreasing) number of challengers can be fairly easily accommodated within the standard framework.

Let c_t , $t = 1, ..,$ be the number of challengers in period t, and let $\lambda_t = \sum_{\tau=1}^{t} c_\tau$ denote the cumulative number of challengers through the end of period t. Then think of a notional sequence with one challenger in every period of notional time. A record break will occur in period t of actual time if and only if a record break occurs in at least one period of notional time between notional period λ_{t-1} and notional period λ_t. So from Renyi's result the probability that no record break will occur in period t of actual time is:

$$\Pi_{k=\lambda_{t-1}}^{\lambda}(1-\frac{1}{k}) = \Pi_{k=\lambda_{t-1}}^{\lambda_t}(\frac{k-1}{k}) = \frac{\lambda_{t-1}}{\lambda_t} \ ,$$

and so the probability of a record break in period t is

$$E_t = 1 - \frac{\lambda_{t-1}}{\lambda_t} = \frac{c_t}{\lambda_t}.$$

Note that if c_t is constant, this probability simplifies to $(1/t)$. With some algebraic manipulation we can show that E_t will be greater than the standard $(1/t)$ if and only if c_t is greater than the average number of challengers to date (λ_t/t). Thus globalization can increase speed of change if it adds challengers fast enough.

We can use the same framework to think about technical progress. Suppose for the moment that there is only one competing technology in every period. Let $F_t(.)$ denote the distribution from which the cost of the challenging technology is drawn in period t; technical change means that $F_t(.)$ is no longer the same for every t. Technical progress, as opposed to just change, means that if $s > t$, $F_s(.)$ is in some sense a better distribution than $F_t(.)$. For some purposes, economists have found it convenient to model technical progress as a decrease in the distribution's mean. However, mean-reducing technical change is not convenient for our purposes.

Instead we will concentrate on what we call "logarithmically proportional" technical change. For $s > t$ we say that technical change between t and s is logarithmically proportional if there is some positive constant $\gamma(t,s)$ such that for all x,

$$ln(1 - F_s(x)) = \gamma(t,s) ln(1 - F_t(x)),$$

that is,

$$1 - F_s(x) = (1 - F_t(x))^{\gamma(t,s)}.$$

If x represents costs so that smaller is better, technical progress means that $\gamma(t,s)$ is greater than one: values greater than x are less probable on future draws than on current draws. Logarithmic proportionality is a restriction on technical progress, but it seems to us no more arbitrary a restriction than mean-reduction.

If technical progress is logarithmically proportional, then for all s and x:

$$1 - F_s(x) = (1 - F_1(x))^{\gamma(1,s)}.$$

This implies that $F_s(.)$ is the same as the distribution of the minimum of $\gamma(1, s)$ draws from the distribution $F_1(.)$. So technical progress (as long as it is logarithmically proportional) is the same as globalization with

$$\gamma(1, s) = \frac{c_s}{c_1} \ .$$

If technical progress is being made,

$$\gamma(s - 1, s) > 1, \text{ and so}$$

$$\gamma(1, s) = \gamma(s - 1, s)\gamma(1, s - 1) > \gamma(1, s - 1).$$

Just like an increase in the number of challengers, technical progress increases the frequency with which records are broken. Thus log proportional technical progress, too, raises the speed of change.

Looking at technical change as a process of more draws rather than as a shifting of means is appropriate in another sense for studying how fast things change; logarithmic proportionality is more than a handy computational assumption. Whatever form technical change takes, what matters to the speed of change is not the change in mean, but the implicit change in the number of draws.

A simple example suffices. Suppose we are concerned with upper records, and two periods. There are two cases. In case A, first period draws are from a uniform distribution on the unit interval $U(0, 1)$, and second period draws are from the distribution of the maximum of the two $U(0, 1)$ variables

$$F_1^A(x) = x$$

$$F_2^A(x) = x^2$$

In case B, first period draws are from a standard exponential distribution, and second period draws are from the distribution of the maximum of two standard exponential variables:

$$F_1^B(x) = 1 - exp(-x)$$

$$F_2^B(x) = (1 - exp(-x))^2$$

Clearly, the speed of change is the same in both cases: the probability is (2/3) that a record will be broken in period two. But the rate of change in the mean is much different: the mean increases from 1/2 to 2/3 in case A, a gain of 33 per cent, while the mean increases from 1 to 3/2 in case B, a gain of 50 per cent. So changes in expected performance are not the relevant focus in the study of the speed of change.

When both globalization and technical progress are occurring, their effects compound. If period t has c_t challengers but technical progress makes each of them as effective as $\gamma(1,t)$ challengers in the first period, then effectively there are: $c_t^* = \gamma(1,t)c_t$ challengers in period t. Defining

$$\lambda_t^* = \sum_{\tau=1}^{t} c_\tau^*,$$

we can reproduce all of our previous results with starred variables.

3 Empirical Results

Track and field has seen impressive technical progress and globalization. Technical progress has included better running surfaces, better shoes and equipment, improved training techniques and nutrition and medical care, the banning of smoking during indoor competition, more accurate recording devices, and softer landing pits for jumps and vaults. Globalization is evident in the emergence of competitors from such areas as East Africa, North Africa, Eastern Europe, China, and the Caribbean countries.

Some records can be broken by anyone in the world, and other records can be broken only by members of defined populations. The former we call global records; the latter local records. If the eligible population for a local record has been fairly constant, then only technical progress can increase speed of change. The extent to which the speed of change in global records rises faster than speed of change in local records is a measure of the contribution of globalization to the total increase in speed of change.

To be specific, we have three series of global records – world, Olympic, Millrose Game records – and two series of local records – US and New Jersey high school (N.J.S.I.A.A.) records. Our starting dates range from 1877 for US men's records to 1958 for NJ high school records.

3.1 The Data

The Olympic data set is easiest to describe. The Olympics have been held every four years (except for additional Olympic Games in 1906 and no Games in 1916, 1940 and 1944) since 1896, and the men's track and field events have not changed often during this period, although some have been added, (for example "50 km walking" in 1932) and some have been dropped (for example "Standing High Jump" in 1912). Women's events were introduced in 1928 and have changed more frequently. The specifications for the javelin changed in 1979 to make it less likely that someone would be able to throw one into the crowd in an enclosed stadium, and so we treat the old javelin and the new javelin as separate events. Our source is the *Information Almanac Please* (1995). We omit the decathlon because scoring tables were revised several times.

Olympic data have two drawbacks. First is that Olympics are held only every four years. This reduces the number of observations we have. Second is the effect of boycotts. The US and many of its allies boycotted the 1980 Olympics, while the Soviet Union and its allies boycotted 1984. These boycotts should have reduced the probability of record performances at these Olympics.

The Millrose data set is similar to the Olympics in that competitions are held on a regular basis. The Millrose Games are an indoor track meet that has been held in New York City every year since 1908. Sometimes called the "indoor Olympics," the Millrose Games have attracted most of the twentieth century's best athletes from around the world (Hillebrand 1995). Few Millrose events have simple histories, but our estimation methods can handle complex histories. As with the other data sets, we consider the metric events of 200 meters, 400 meters, and 800 meters equivalent to the imperial 220 yards, 440 yards and 880 yards , respectively, but otherwise consider different distances and different weights to be different events. We have data for 33 Millrose events (not including high school events).

The chief problem is that participation in the Millrose Games by the world's best athletes varies from year to year. Indoor meets compete with each other on a number of dimensions – publicity, prizes, and appearance fees, for instance, and in some years Millrose has been more attractive to athletes than in other years. Since for most of the period under study much of the competition among indoor track meets was "under the table", we have no way of measuring the ups and downs of Millrose's relative attractiveness.

Millrose data also provide us with a small local data set. Since World

War II, the meet has included a number of events for high school students – some restricted to certain types of schools in the metropolitan area, others open to select students from throughout the US. We have data for 11 high school events.

World records are our final global series. We use International Amateur Athletic Foundation (IAAF) records for men from 1912, Women's International Sports Federation (FIFA) records for women from 1922 to 1935, and IAAF women's records thereafter. The source for these records is Hymans (1995). We omit indoor events, because IAAF records are fragmentary, and several events that are not competed frequently (e.g. 8 miles, women's pole vault). The IAAF discontinued records for imperial distances, except the mile, in 1976, and we reflect this discontinuance. We consider only official certified records – that is, we define as part of the event the maintenance of conditions sufficient to achieve IAAF certification. In some cases – having amateur status, proper recording of lap times, submission of adequate paperwork – putative records have been rejected for reasons that might strike us as trivial, but we do not intend to pick and choose among performances on *ad hoc* criteria. We also use contemporaneous rules (so, for instance, while it is almost certain that the many records Stella Walsh set in the 1920s and 1930s would be rejected today because of her controversial gender status, we accept them because FIFA accepted them).

In all, we use IAAF and FIFA world record progressions for 69 different events, 28 for men and 41 for women. These records have two kinds of problems. The first problem is the waxing and waning of various events' popularity. Ideally, the number of "periods" should be the number of times an event is contested, but we do not have any information about this. For the sake of consistency with our other data, we take a period to be a calendar year; thus if a record is broken several times within the same calendar year we count only the last break. Unfortunately, this procedure implies that we may sometimes mistake a change in convention for globalization or technical progress. For instance, if meet promoters stop holding mile races and start holding 1500 meter races instead, record progression will slow down at the mile and speed up at 1500 meters, even if no other changes occur. All of our estimating procedures, however, rely on grouping many similar events together, and grouping may eliminate a good deal of this problem.

The second problem is the total number of competitions. Since an individual athlete's level of performance varies from day to day, the more often she competes under world-record-certifiable conditions, the better her expected best performance of the year. More competition could increase the speed of change, without either more competitors or technical progress. However for some events (distance running especially), physiological recovery limits the number of events on which an athlete can concentrate intensely. To the extent these limits, rather than the limits imposed by meet organization, are the binding ones for athletes capable of breaking world records, the distortion caused by changing numbers of competitive venues may be small. The distortion would also be reduced if intra-athlete variation is very small relative to inter-athlete variation.

Where the problem of number of competitions is particularly acute is at the beginning of the IAAF series (and to a lesser extent at the beginning of the FIFA series). Remember that the only competitions that concern us are those that meet stringent (and possibly in some cases quirky) IAAF standards, and for which proper documentation has been submitted. Years may go by between such competitions. For example, the first official record in the hammer throw was established in 1913, the first in 220 yards in 1896. Part of the technical progress and globalization we observe in IAAF records, therefore, particularly those in the early part of the century, reflects better performance by track and field officials, not better performance by athletes. Since our real interest is in applications to economics, not in understanding athletes, better performance by officials seems just as relevant as better performance by athletes, and so we see no reason to try to correct for it (indeed, since officials' work is probably more similar to ordinary people's work than athletes' work is, better work by officials may be more relevant to our larger concerns than better work by athletes).

Our largest local data set is US. records, for which we primarily use Davis and Carey (1983) for men and Davis and Carey (1991) for women. These volumes cover 1877-1983 for men and 1892-1991 for women. We updated the men's series to 1994 from the *Information Please Almanac* (1995). We do not consider indoor records, and omitted the decathlon. Like the IAAF, US authorities discontinued imperial distance records in 1974. In all we have 40 events, 20 for men and 20 for women.

Since they are not tied to specific meets held at regular intervals, US records have the same problems with event popularity and number of competitions that IAAF records do. Because US. procedures were standardized earlier than IAAF procedures were (nineteenth century records are essentially derived from the annual best lists of the "New York Clipper" for men, and from Seven Sisters college field days for women), early progress probably reflects higher ratio of athlete to official improvement than the IAAF records do.

As a purely local series, moreover, designed to reflect only technical progress, US records have two other problems. The first is the growth of US population – resident population grew from 55 million in 1880 to 263 million in 1995. The second is the exclusion of most African-Americans from track and field in the early years of our data, and their growing involvement after the 1920s. We will attempt to control for population growth, but it is difficult to look separately at events in which African Americans are currently dominant. In a sense, "globalization" has been occurring within US borders for the last 120 years (at least), and this trend would increase the speed of change experienced by US citizens even if the US were autarkic.

Our other local data set are the records of the New Jersey State Interscholastic Athletic Association (NJSIAA). The NJSIAA has been conducting New Jersey high school championship meets since 1919 (Fitzgerald's Legislative Manual, 1994, p.563). We examined the results of these championship meets from 1958 through 1994 and constructed record progressions based on these results (The 1968 results are missing, but 1969 information indicated only one record was set in 1968, for the half-mile.) We include 24 events for boys and 25 events for girls. Girls' meets started in 1972.

The record progression that we constructed differs from the record progression the NJSIAA publishes in several ways. First, in our primary analysis we ignore all records set before 1958 because we do not have enough information about those records; we start 1958 with a clean slate. The NJSIAA's 1958 publication lists records standing as of 1958 and the date when they were set; we can perform certain calculations with this table, but these calculations will be separate from our main analysis. Second, we count only the final championship meet of the year. In different years the NJSIAA has conducted different combinations of sectional, group, and grand championship meets. For girls in 1972, we use the best performance from four separate simultaneous sectional championships; for 1973 we use the better from two separate simultaneous group championships; and after that we use the results of the grand championships.

Since we use only one meet per year and have a definite starting point, this time series shares most of the desirable properties of the Millrose and Olympic series. Moreover, there have been no boycotts of the NJSIAA meets, and little fluctuation in their popularity: all high school stars participate, although sometimes they may concentrate on other venues like the Olympics. As a local series, moreover, the NJSIAA has several advantages over the US records. New Jersey high schools did not have *de jure* discrimination after 1947. Common technical advances are highly likely to show up quickly in New Jersey high schools: the state had the second highest per capita income in 1994, the fifth highest proportion of college graduates in 1990, and the second highest per student expenditure in 1996.

All of these data sets have a common problem, especially for the sprints, in the evolution of timing technology. At the turn of the century timing devices were crude, coarse – reporting results only to the nearest fifth of a second –, and untrustworthy. Accuracy increased over the next seven decades as both timing devices and the training of officials improved. For instance, records started being reported in the tenths of a second around 1910. In the 1970's, electronic timing was initiated. This improved accuracy still further and allowed results to be reported in hundredths of a second.

How do these changes affect the rate at which records are being broken? Two forces work in different directions. On one hand, the smaller the unit of reporting, the smaller the margin by which a record must be broken to be discerned, and so the faster records fall. On the other hand, measurement error decreases from year to year imply reductions in the variance of performances, and *ceteris paribus*, assuming measurement errors are uncorrelated with underlying true performances, such year-to-year variance reductions slow the rate at which records are broken. Thus timing improvements after 1910 should slow record progress, with a large one-time slowing on the introduction of electronic timing, but after this one-time slowing progress should be faster than it was before electronic timing. This pattern should be significant in the sprints, but not in other events. Since a large fraction of the events in which African Americans are currently dominant are sprints, these difficulties with timing technology are what make it impossible to separate out the consequences of the African American entry into track and field competition.

3.2 Nonparametric Estimates

Our first step was to try to estimate the (c_t) sequence for each of the five record sets. To fix ideas, consider a sequence of observations of a large set of events that all have the same starting point. We are not fortunate enough to have any such set, but this exercise will give the intuition for the procedures we use. Let $f_t,\ t = 2, ..., T$ denote the empirical proportion of records that are broken in period t. Recall that the record indicator for period t is a Bernoulli variable with parameter

$$E_t = \frac{c_t}{\lambda_t}.$$

Thus f_t is an unbiased estimator of E_t. Consider the following estimates

$$\hat{c}_1 := 1; \text{ and}$$

$$\hat{c}_t = \frac{f_t}{(1-f_t)}\hat{\lambda}_{t-1} \text{ (where } \hat{\lambda}_{t-1} = \sum_{\tau=1}^{t} \hat{c}_\tau). \tag{1}$$

This implies

$$f_t = \frac{\hat{c}_t}{\hat{\lambda}_t}.$$

Unfortunately, when different events start at different times – as they do in all our data sets – somewhat modified procedures are needed. Call the events that started at time $(T+1)$ the events of cohort T (so the earliest events are those of cohort 0). Let $\lambda_0 = 0$, and denote $\lambda_{tT} = \lambda - \lambda_T$. So the probability of a record break at time t in an event of cohort T, $T < t$, is $\frac{c_t}{\lambda_{tT}}$.

Empirically, let b_{tT} denote the number of record breaks in cohort T at time t, and let n_{tT} denote the number of events in cohort T. Let $\hat{c}_{tT}$ denote the maximum likelihood estimate we would make for period t if we were concerned only with cohort T:

$$\hat{c}_{tT} = \frac{b_{tT}}{(n_{tT} - b_{tT})}\hat{\lambda}_{tT}$$

which is the same as f_t specialized to cohort T. If at each time t, $\hat{c}_{tT}$ were the same for every active cohort T, then we could use the simple procedures that worked with a single cohort. But there is no guarantee that the $\hat{c}_{tT}$ will be the same. Thus we must maximize likelihood explicitly. Let $L_{tT}(\hat{c})$ denote the log likelihood of precisely b_{tT} record breaks in period t for cohort T with parameters $\hat{c} = (\hat{c}_t)$:

$$L_{tT}(\hat{c}_t) = ln(\frac{n_{tT}}{b_{tT}}) + b_{tT}\ ln\hat{c}_t + (n_{tT} - b_{tT})ln\hat{\lambda}_{t-1,T} - n_{tT}\ ln\hat{\lambda}_{tT}$$

Then the object is to choose a vector $\hat{c}$ to maximize:

$$L(\hat{c}) = \sum_t \sum_{T \le t+2} L_{tT}(\hat{c})\ .$$

This is the likelihood expression we attempted to maximize. Figure 1 presents our results for Millrose Games and NJSIAA. This figure presents five-year centered moving averages with c_{1958} normalized to one for both series. Technical progress is evident, as both series trend upward. Millrose appears to have more progress: either globalization is at work, or technical change is biased.

One weakness of our estimating procedure is that precision decreases as time increases. This should be evident from (1) where uncertainty compounds on each iteration. Since we have more interest in later years than early ones, this weakness presents a serious problem. One way to address this problem partially is to run time backwards: since our theory is based on an underlying series of notional i.i.d. draws, it makes no difference whether time runs backwards or forwards. Thus figure 2 presents the same information as figure 1, but calculated with time running backward. There is no major change in the interpretation.

The most serious problem with nonparametric estimates is that for world and American records and the Olympics, the estimates of c_t become too big for our computing capacity to handle. We cannot run world and American records backwards because we do not observe performances in each year and so cannot construct a backwards record series.

3.3 Polynomial estimates

Accordingly, we decided to impose a functional form on c_t and estimate parameters of that form. For the two functional forms we considered, it is easier to approximate time as a continuous variable rather than as a discrete one. Discrete time versions are easily derived and have the same properties. Our first functional form is polynomial:

$$c_t = \int_{t-1}^{t} \tau^{\beta} d\tau$$

where β is a parameter we will attempt to fit for each of the five series. For an athletic event which we have complete observations for

$$\lambda_t = \int_{0}^{t} \tau^{\beta} d\tau = (\beta+1)^{-1} t^{\beta+1}$$

and so the probability of a record break at time t is

$$E_t = \frac{c_t}{\lambda_t} = \frac{t^{\beta+1} - (t-1)^{\beta+1}}{t^{\beta+1}} = 1 - (\frac{t-1}{t})^{\beta+1} \qquad (2)$$

Similarly, for an event that started at time $T > 0$, the probability of a record break at time T is

$$E_t = \frac{c_t}{\lambda_t - \lambda_T} = \frac{(\beta+1)^{-1}(t^{\beta+1} - (t-1)^{\beta+1})}{(\beta+1)^{-1}t^{\beta+1} - (\beta+1)^{-1}T^{\beta+1}} =$$

$$= (1 - (\frac{t-1}{t})^{\beta+1})\frac{1}{1-(\frac{T}{t})^{\beta+1}}$$

which is the expression we estimate by maximum likelihood.

Our estimates for β are 0.4018 (0.194 s.e.) for NJSIAA and 4.1975 (0.460 s.e.) for Millrose. The important thing about both of these estimates is that both allow us to reject the hypothesis that $\beta \leq 0$. For Millrose c_ts are increasing at an increasing rate.

For world, US, and Olympic records our estimates failed to converge; again the numbers became too large. It is easy to see the problem with the polynomial functional form. From (2), note that as t goes to infinity, the probability of a record break goes to zero. But in the data, even for very old series, records keep being broken. We need a functional form that allows faster than polynomial growth.

3.4 Exponential estimates

Accordingly we next tried the exponential functional form

$$c_t = \int_{t-1}^{t} exp(\alpha\tau)d\tau = \frac{1}{\alpha}(exp(\alpha t) - exp(\alpha(t-1)))$$

where α is the parameter we will estimate. For an athletic event for which we have complete observations

$$\lambda_t = \int_0^t exp(\alpha\tau)d\tau = \frac{1}{\alpha}(exp(\alpha t) - 1)$$

and so

$$E_t = \frac{c_t}{\lambda_t} = \frac{1 - exp(-\alpha)}{(1 - exp(\alpha t))}$$

Thus the probability of a record break is monotonically decreasing over time, but asymptotes to $1 - exp(-\alpha) \cong \alpha$, not zero. Continuing nontrivial proportions of record breaks are compatible with exponential growth.

For an event that began at time T:

$$E_t = \frac{c_t}{\lambda_t - \lambda_T} = \frac{1 - exp(-\alpha)}{1 - (exp(-\alpha(t-T))} \quad (3)$$

which is the expression we estimate by maximum likelihood. We were able to compute estimates for each of the five time series. These are presented in table 1. (We divided the Olympic estimate by 4 to be comparable with the other estimates, since the Olympics are held only every fourth year.)

Table 1 confirms some of our expectations. The underlying process for world records improves more quickly than the underlying process for US records and the underlying process for NJSIAA records. Globalization increases the speed of change. Neither Olympic records nor Millrose records rise as quickly as world records. Meet competition and boycotts appear to make a difference too.

But the difference between world and US records is surprisingly small, statistically insignificant, while the difference between US and NJSIAA records is surprisingly large. Table 1 suggests that globalization is not a very important part of the speed of change, but that either biased technical change or "domestic globalization" – the entry of previously excluded American groups into competition in the US – does matter.

3.5 Additional explanatory variables

We need to explore this issue further. Fortunately the exponential functional form lets us do so quite easily. There is no reason to force α to be constant across all events and years. Let

$$\alpha_{it} = \sum_j \alpha_j^* X_{itj}$$

for event i and time j, where X_{itj} is the value of the j-th explanatory variable at time t and event j. Then from the appropriate analogue of (3) we can estimate the α_j^* and explain the rate at which the record process is changing.

There are a number of different explanatory variables we have examined:

- OBSCURE Certain events, especially in the world record series, are competed fairly infrequently – for instance, the hour and the two-mile run. We expect records for these events to be broken less frequently. Accordingly we constructed a dummy variable OBSCURE taking on a value of 1 for obscure events, 0 otherwise[1]. We expect the coefficient of OBSCURE to be negative.

- WAR We expect wars to hurt performance. We construct a dummy variable WAR1 for the period (1914-1918) and a dummy variable WAR2 for the period (1938-1948). We expect the coefficient on both variables to be negative.

- US-POP population has been far from being static over time. Immigration as well as baby boom and bust periods had a significant effect on the size of youth cohorts and thus on the pool of potential competitors. We use decade growth rates of the civilian population age 20-35 to proxy these developments. Almost all records are broken by people in this age range. High growth rates should show up in increased as record progression rates.

- HEALTH Health status is a second important component. Lacking an adequate measure for the improvements in nutrition, and advances in medical treatment we use the growth rate of life expectancy as a summary measure. We expect improvements in life expectancy to have a positive effect on record progression.

- RECESSION To find out whether macroeconomic conditions affect athletic performance and technical progress we constructed a dummy variable RECESSION=1 for years in which two or more quarters were NBER recessions. We used this variable for US and Millrose records.

- FEMALE Women's participation in and commitment to athletics may have been growing faster than men's. We construct a dummy variable FEMALE=1 for women's events. We expect the coefficient to be positive.

- HAND As we argued in the text, improvements in hand-timing technique may have slowed down the rate of record breaking in the sprint. We create a variable HAND=1 for distances less than or equal to 400 meters for the era of hand timing and tenth-of-a-second recording, 1910-1975.

[1]Obscure events are 50 metres, 80 metres, 2000m, 3000m, 2 miles, 3 miles, 1 hour, 80 metres hurdles, 3 x 800m relay, 1000 metres relay, 1200 metres relay, standing high jump, standing long jump, shot put both hands, discus both hands, javelin both hands, 200 metres hurdles, 20 kilometres, 30 kilometres, 50 kilometres, 2 hours.

- DECADES We create decade dummies for each decade from 1920s on. The excluded variable is pre-1920.
- HIGHSCHOOL For Millrose estimates, we include a variable to designate high school events to check how robust are results about NJSIAA were. A large negative coefficient would confirm the difference between the US and NJSIAA results in table 1.
- ENROLLMENT and GRADUATION To capture local trends, we collected data on the number of students enrolled in NJ public high schools (ENROLLMENT) and the number of students graduating (GRADUATION), since high school records are most likely to be set by students in their final year. Enrollment and graduation fell in the 1970s and 1980s. (Accurate figures are not available for private schools, although most private schools participate in the NJSIAA.) This should have slowed New Jersey record progression and may explain part of the gap between NJSIAA and US records.

Results of these regressions are presented in table 2: table 2a for Millrose, 2b for NJSIAA, 2c for US, 2d for world, and 2e for Olympic. Figure 3a summarizes part of these results by plotting over time the value of alpha for a non hand-timed, men's, non-obscure event in peace and prosperity for world, US, and NJSIAA. Figure 3b contrasts US, world, and NJSIAA events for men in peace and prosperity with constant population and no changes in high school graduation rates. The graphs are based on estimates reported in Table 3a and 3b.

Table 2 does not noticeably change the conclusions from table 1. The poor showing of NJSIAA (Table 2b) is not because the series starts only in 1958; quite the contrary, periods of greatest growth for world and US were after 1958. HAND-timing and gender have the expected signs, but are not very strong in significance. There is remarkable negative effect of the decline in HS graduations. The base line record progression rate α rises to 0.091. This narrows the gap between New Jersey and US record progression, but does not eliminate it.

Several other variables performed as expected. War is bad, and so is obscurity (Tables 2a, 2c, and 2d). Recessions reduce record progression for US events but are not significant in the Millrose Games. Women do better than men in the world, but somewhat surprisingly, the difference is small in the US. Further analysis showed, however, that almost all the female premium in the world record series is due to the weight events. Also life expectancy and population growth have expected signs. They reduce the US α somewhat (25 per cent), but cannot account for much of the gap between New Jersey and US records.

The time trend is not monotonic, and the 1980s and 1990s are in fact not outstanding. The best decades in the US series are 1950s and 1960s; the best decades in the world are 1970s and 1950s. Our data do not support faster change from any source since 1980.

3.6 Retrospective analysis

Since our finding of slow technological progress in the NJSIAA series is surprising, we attempted to bring additional data to bear on it. As an additional piece of information we use existing NJSIAA records of 1958.

For this type of data the technique for estimating record progression rates is somewhat different from the one we have been examining. For NJSIAA, we observe in 1958 the records that existed then and the years they were set. Assume that all the NJSIAA events we observed in 1958 started in 1919 and were competed without interruption (this biases up our estimate of the rate of technical progress). A record set in 1933 will remain in 1958 if and only if it is the best of all performances between 1919 and 1958. In the absence of technical progress – that is, in the i.i.d. setting – the probability of a 1933 record would be 1/39, since every year is equally likely to contain the best performance. With technical progress, the probability of a 1933 record is simply the number of draws in 1933 divided by the total number of draws between 1919 and 1958. Thus with exponential functional form, the probability of observing in year T a record set in year $t \leq T$ is

$$\frac{exp(\alpha t)}{\int_0^T exp(\alpha\tau)d\tau} = \frac{1 - exp(-\alpha)}{exp(-\alpha(t-T)) - exp(-\alpha t)}$$

which we fit by maximum likelihood. Our estimate for α from the 1958 records is 0.0857 (0.0028) this becomes 0.112 (0.034) if we assume no competition for 1942-1946. These slightly higher numbers indicate that more record breaks were made in the pre-1958 period and thereby reduces but does not eliminate the overall difference between the local and national games. Recall, however, that 1919-1958 is a period of rapidly rising high school enrollment and graduation.

A final check is to look at high school events in the Millrose Games. From Table 2a, the base line rate for these events in peace and prosperity is about 0.10 - 0.11 depending on what else is being controlled for. This is not out of the line with our NJ high school results, and further confirms large differences between high schools and US national records.

4 Conclusion

There has been real progress in track and field at all levels of competition, although the rate of progress recently is certainly no greater than it was in the 50s and 60s, and probably, slightly less. New Jersey high school records, however, progress much more slowly than US records. Thus either technical progress is biased toward elite and experienced athletes or "domestic globalization" is important.

Some of this paper's contributions reject some common beliefs. In track and field globalization is not making change more rapid. Change is not more rapid, and whatever it is that is driving the process we observe can be found almost entirely within the borders of the United States.

On the positive side, the paper suggests two directions for future research. One is trying to explain divergence between NJ and the nation. High school records for other states would be helpful here. "Domestic globalization" is a hypothesis that deserves further study.

Measuring the speed of record breaks is clearly of great interest to track and field fans. But our findings are also of interest to economists. The major contribution of the paper, we hope, is to bring the theory of records to the attention of the economics profession. Records are statistics of optimization, and so it is natural that they should appear repeatedly in economics. To understand how fast things change, records are the obvious tool. For instance, if people switch jobs whenever they get a better offer, and offers are stochastic (Burdett, 1978), then job durations are distributed as inter-record times or turnover is distributed as a record break. Consider the following areas.

4.1 Technical progress and globalization

The relative importance of globalization and of technical progress in explaining changes in US. and European income distributions has been a major topic of debate for close to a decade. One major weakness in the debate has been the absence of direct measures of either globalization or of technical progress.

Track and field records offer such direct measures. We look at several different record progressions – for instance, world records and records in

New Jersey high school championship meets. Since the latter is unlikely to be affected by globalization while the former is, a difference-in-differences approach lets us evaluate the relative importance of technological progress and globalization.

Of course, track and field is only one area of human endeavor. It would be better if we had similar information from many other areas of endeavor, and from areas much more central to modern economic life. But we don't. Only weather records have been kept for a somewhat longer time than track and field records have, but weather has probably not been so affected by technical progress (except possibly for the development of instruments that permit finer measurement) and globalization. A sample of one, while not definitive, is clearly more informative than a sample of zero.

It might be objected that track and field is different from more central economic activities because performance in track and field is bounded by human capabilities. We disagree vehemently. Throwing a javelin is a human endeavor, a physical activity; so is writing software (or designing machines to write software). People are getting better at doing both (our data show that this is true for throwing the javelin),[2] and there is no evidence to support the notion that limits are binding in either activity.[3]

4.2 Speed of discrete change

Rapid discrete changes have many implications for questions of great interest to economists. It is often claimed, for instance, that jobs are being destroyed more frequently than before, that events which seemed far away – like regional economic crises – suddenly affect daily life, and that new technologies fundamentally alter basic economic routines.

Farber (1995) and Idson and Valetta (1996) have shown that the rate of job loss among skilled Americans has risen modestly since 1980. Incomes have also become more unstable (Levy and Murnane 1991). Beyond these solid empirical demonstrations of modestly rising volatility, the media (e.g.,

[2] Fogel (1994) demonstrates that, considered simply as physical beings, humans today are a radically improved version of humans two centuries ago.

[3] Another objection might be that the absence of a direct profit motive means that participants in track and field are less highly motivated than participants in other areas of economic life. There is ample evidence that this is not the case. The rewards, both pecuniary and nonpecuniary, to superior performance in track and field have always been considerable; international track and field meets have always been closer to a business than a pure exhibition of talent. Track and field also parallels the larger economy in the rise of superstars, as described in Rosen (1983).

New York Times, 1996) have either reported or created a new fear of job insecurity and change in middle class Americans.

If life changes more quickly, being able to adjust well to change becomes a more valuable attribute, and people who have it will be better rewarded in the market. College-educated workers may adjust to change better, and so the speed of change may be driving part of the rise in the college premium (see Griliches (1969), Nelson and Phelps (1966), Bhagwati and Dehejia (1995)). The rising return to unobserved dimensions of skill (Juhn et al. (1993)) may also reflect an ability to adapt better to change; indeed Bartel and Sicherman (1997) show that most of the higher wages workers receive in industries undergoing rapid technological change is due to unobserved skills they possess.

Thus it is important to be able to think about how fast new venues and modes of production replace old ones. This is where the theory of record processes help.

Nobody doubts that things change, but it is less clear at what pace they do, and whether these changes have speeded up in recent years. Our paper directly addressed these two issues. We introduced a benchmark case of discrete change by defining the speed of change in a world with i.i.d. draws from the same distribution. In our model acceleration of change was measured as the deviation from this process.

Ideally, we would like to look at records for activities like making cars well and writing good software, and see whether these records are being broken faster. But this is impossible; in part because it is not always clear what "better" means in these areas. Here we confront another great advantage of track and field records – what "better" means is unambiguous and simple to measure. We can see whether or not track and field records are being broken faster, and in the absence of similar direct information about other areas, this sample of one once again is informative.

A priori, it is unclear whether technical progress in track and field might be expected to be faster or slower than technical progress in other fields of human endeavor. On the one hand, the rules of track and field place many restrictions on the ways in which technical progress can be made.[4] For instance, you cannot improve your performance in the long jump by using a raised take-off board, or placing a big fan behind you in the runway, or injecting copious amounts of steroids. Since most other areas of human endeavor do not operate under such restrictive rules, one might ex-

[4] We are grateful to Rajiv Sethi for raising this issue with us.

pect technical progress to be slower in track and field. On the other hand, the objective function in track and field is much simpler than the objective function in most other areas. A new type of car engine will be evaluated not only on the basis of whether it makes a car go faster, but also on whether it produces an acceptably smooth ride, acceptably low pollution, a good-looking car, and so on. A new way of training for the 1500-meter run on the other hand need only produce faster times. So technical progress might be faster in track and field for this reason.[5]

4.3 Method of estimation

We believe that this paper is the first to estimate the parameters of non i.i.d. record processes. The empirical techniques we develop for studying track and field records may also prove helpful for other problems that economists study. In many areas of economic life, people do things a certain way until something better comes along. Physicians injected Salk polio vaccine until oral Sabin vaccine was invented; they adhered to the stress theory of ulcer causation until the bacteria theory triumphed. People stopped buying vinyl when CDs become available. Abelard was true to his vows until Heloise came along. Most African Americans stopped supporting the Republican Party when Eleanor and Franklin Roosevelt convinced them the Democrats had more to offer. On an individual level, consumers stick to their favorite brands of soda, running shoes, pretzels, and cars, until they find brands they like better.

If people stick to the old ways until they find something better, the theory of record processes explains how often they change. That is how we link records and international trade: at any moment the region producing automobiles for the US. market, say, should be the region that can do so most cheaply (in relative terms); so switches in the origin of automobiles should occur only when another region finds it can produce more cheaply (always in relative terms). A change in the origin of US. automobiles is like a record break: a new region can produce more cheaply than all previous regions.

Thus track and field, technical progress, and international trade are not

[5]The lagrangian transformation shows that every constrained optimization problem with a single objective (e.g. a track and field problem) is equivalent to an unconstrained optimization problem of the weighted sum of multiple objectives (e.g., a car design problem). This is the deeper reason why it does not seem possible to guess a priori which sort of problem should be more amenable to progress through innovation.

the only areas where switches are like record breaks. The theory of records processes also carries testable predictions about how often people will change jobs, drugs, marriage partners, brands of soda, and political affiliation.

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Table 1: Exponential Estimates

Data	α	S.E.
New Jersey HS	0.0578	0.0215
Millrose	0.162	0.0163
US Records	0.2472	0.0102
World Records	0.259	0.0094
Olympic Games	0.2135	0.0124

Table 2a: Millrose Games (1915-1993) n=973

Millrose	est	est	est	est	est
constant	0.179	0.176	0.189	0.254	0.184
	(0.016)	(0.016)	(0.016)	(0.015)	(0.016)
obscure					
war1					
war2	-0.092	-0.025	-0.079		-0.034
	(-0.034)	(0.060)	(0.035)		(0.061)
hand timing	-0.025	-0.090	-0.037	-0.153	-0.079
	(0.059)	(0.035)	(0.060)	(0.037)	(0.036)
female		0.009			0.002
		(0.027)			(0.029)
Highschool			-0.079		-0.079
			(0.042)		(0.044)
Recession					0.027
					(0.046)
1920-1930					
1930-1940					
1940-1950				-0.130	
				(0.062)	
1950-1960				-0.014	
				(0.050)	
1960-1970				0.068	
				(0.053)	
1970-1980				-0.124	
				(0.037)	
1980-1990				-0.050	
				(0.049)	
1990-1995				-0.256	
				(0.068)	
Log Lik	-455.32	-455.2	-453.7	-439.79	

Note: The omitted category for the decade dummies are the years between 1915-1939. Standard errors in parenthesis.

Table 2b: New Jersey High School (1958-1993) n=692

N.J. HS	est	est	est	est	est	est	est
constant	0.056	0.042	0.0912	0.079	0.073	0.061	0.240
	(0.021)	(0.021)	(0.023)	(0.024)	(0.023)	(0.023)	(0.022)
obscure							
war1							
war2							
hand timing	0.011	0.023	-0.042	-0.005	-0.039	0.0056	-0.141
	(0.070)	(0.070)	(0.069)	(0.089)	(0.069)	(0.064)	(0.069)
female		0.051			0.100	0.080	
		(0.051)			(0.060)	(0.060)	
Highschool							
Enrollment			0.726		1.111		
			(0.857)		(0.887)		
Graduation				-0.137		-0.049	
				(0.598)		(3.155)	
1920-1930							
1930-1940							
1940-1950							
1950-1960							
1960-1970							
1970-1980							-0.059
							(0.053)
1980-1990							-0.241
							(0.051)
1990-1995							-0.262
							(0.089)
log lik	-320.4	-319.9	-303.9	-304.9	-302.5	-303.3	-311.81

Note: Estimation models involving the variables "enrollment and graduation growth rate" use data only up to 1990. Standard errors in parenthesis.

Table 2c: US records (1876-1991) n=3026

US records	est	est	est	est	est	est	est
constant	0.299	0.304	0.318	0.259	0.258	0.278	0.223
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
obscure							
war1	-0.255	-0.259	-0.254	-0.255	-0.240	-0.240	
	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	
war2	-0.212	-0.216	-0.224	-0.212	-0.192	-0.204	
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	
hand timing	-0.061	-0.060	-0.065	-0.061	-0.059	-0.063	-0.079
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.020)
female		-0.017					
		(0.021)					
Highschool							
Recession			-0.054			-0.050	
			(0.021)			(0.020)	
Life Exp Grwth				10.030			
				(3.162)			
US-pop Grwth					0.262	0.255	
					(0.090)	(0.091)	
1920-1930							0.042
							(0.034)
1930-1940							0.008
							(0.035)
1940-1950							-0.117
							(0.023)
1950-1960							0.105
							(0.037)
1960-1970							0.203
							(0.043)
1970-1980							0.120
							(0.039)
1980-1990							0.059
							(0.035)
1990-1995							-0.154
							(0.040)
Log Lik	-1557.1	-1556.7	-1554	-1557	-1553.1	-1550.1	-1556.2

Table 2d: World records (1896-1992) n=3767

World records	est	est	est
constant	0.329	0.307	-0.124
	(0.009)	(0.009)	(0.009)
obscure	-0.055	-0.066	-0.057
	(0.021)	(0.021)	(0.020)
war1	-0.637	-0.620	
	(0.119)	(0.120)	
war2	-0.142	-0.133	
	(0.021)	(0.021)	
hand timing	-0.114	-0.116	-0.140
	(0.021)	(0.020)	(0.021)
female		0.060	
		(0.060)	
Highschool			
1920-1930			0.400
			(0.032)
1930-1940			0.408
			(0.027)
1940-1950			0.349
			(0.024)
1950-1960			0.599
			(0.036)
1960-1970			0.512
			(0.034)
1970-1980			0.567
			(0.038)
1980-1990			0.368
			(0.036)
1990-1995			0.284
			(0.063)
Log Lik	-1988	-1983.3	-1942.3

Note: Standard errors in parenthesis.

Table 2e: Olympic records (1896-1992) n=654

Olympic Games	est	est	est	est
constant	0.216	0.192	0.231	0.158
	(0.012)	(0.012)	(0.012)	(0.011)
obscure				
war1				
war2				
hand timing	-0.018	-0.012	-0.032	-0.099
	(0.031)	(0.030)	(0.031)	(0.030)
female		0.091		
		(0.031)		
boycott			-0.080	
			(0.031)	
1920-1930				
1930-1940				0.206
				(0.060)
1940-1950				0.006
				(0.042)
1950-1960				0.242
				(0.061)
1960-1970				0.247
				(0.048)
1970-1980				0.071
				(0.038)
1980-1990				0.022
				(0.030)
1990-1995				-0.094
				(0.034)
Log Lik	-412.3	-407.4	-409.2	-376.8

Note: Standard errors in parenthesis.

Table 3a: Estimates for US, World and NJ Highschool records in Figure 3a

	US	World	NJ HS
constant	0.2715	-0.0440	0.0043
	(0.0092)	(0.0092)	(0.0236)
obscure	0.1965	-0.0647	
	(0.2013)	(0.0206)	
war1	-0.2229	-0.2616	
	(0.0366)	(0.1202)	
war2	-0.0004	-0.0799	
	(0.0245)	(0.0295)	
hand timing	-0.0653	-0.1503	-0.1280
	(0.0207)	(0.0213)	(0.0694)
female	-0.0331	0.0461	0.1146
	(0.0206)	(0.0191)	(0.0592)
1920-1930	0.0021	0.3147	
	(0.0257)	(0.0319)	
1930-1940	-0.0376	0.3233	
	(0.0299)	(0.0269)	
1940-1950	-0.1676	0.2954	
	(0.0268)	(0.0321)	
1950-1960	0.0647	0.5028	
	(0.0367)	(0.0369)	
1960-1970	0.1619	0.4199	0.2289
	(0.0428)	(0.0341)	(0.0785)
1970-1980	0.0833	0.4653	0.1491
	(0.0393)	(0.0385)	(0.0567)
1980-1990	0.0332	0.2671	-0.0295*
	(0.0331)	(0.0361)	(0.2298)
1990-1995	-0.1893	0.1885	
	(0.0400)	(0.0697)	
Log Lik	-1544.0	-1935.6	-295.7

Note: Standard errors in parenthesis. * Decade dummy includes also observations from 1990s

Table 3b: Estimates for US, World and NJ Highschool records in Figure 3b

	US	World	NJ HS
constant	0.2452	0.1671	-0.0065
	(0.0092)	(0.0092)	(0.0278)
obscur	0.1592	-0.0686	
	(0.2034)	(0.0204)	
war1	-0.1973	-0.4737	
	(0.0371)	(0.1205)	
war2	-0.0621	-0.0510	
	(0.0284)	(0.0294)	
hand timing	-0.0763	-0.1489	-0.0464
	(0.0206)	(0.0211)	(0.0728)
female	-0.0388	0.0574	0.1292
	(0.0204)	(0.0198)	(0.0633)
US-pop Grwth	0.0691		
	(0.0661)		
Graduation			-0.6345
			(0.3254)
1925-1935	0.0745	0.1357	
	(0.0347)	(0.0288)	
1935-1945	-0.0650	0.0559	
	(0.0328)	(0.0310)	
1945-1955	-0.1055	0.1069	
	(0.0288)	(0.0271)	
1955-1965	0.2070	0.2810	
	(0.0414)	(0.0354)	
1965-1975	0.0848	0.1903	0.1621
	(0.0465)	(0.0328)	(0.0715)
1975-1985	0.1432	0.1664	0.1496
	(0.0390)	(0.0354)	(0.0695)
1985-1995	-0.0621	-0.0031	-0.1502
	(0.0412)	(0.0287)	(1.5062)
Log Lik	-1530.5	-1943.8	-290.39

Note: Decade dummies have been altered to avoid multicollinearity with decade US population growth data.