Globalization and the Rate of Technological Progress: What Track and Field Records Show

Lalith Munasinghe

Barnard College, Columbia University

Brendan O'Flaherty

Columbia University

Stephan Danninger

International Monetary Fund

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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I. 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 and 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 (such as 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 the latest results from the science of sports physiology see almost immediate application.

Both technological change and globalization have plausibly 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 compare two sets of data: (1) international records that can be set by anyone in the world (world, Olympic, and Millrose records) and (2) local records that can be set only by members of a fixed population (United States and New Jersey high school [NJHS] records). International records should reflect the contribution of both globalization and technological change, but local records should reflect only technological change. The difference between improvements in international records and those in local records should give us an estimate of the effect of globalization.

To summarize our results, the processes driving world records are improving only about 7 percent faster than the processes driving U.S. records, and so the comparison with U.S. 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 NJHS records. These records are improving much more slowly than U.S. records. If we use the world-NJHS difference as our estimate of globalization instead of the world–United States difference, then our conclusion is reversed.

New Jersey high school records are set by adolescents with only a few years of experience in track and full-time school responsibilities. By contrast, U.S. and world records are usually set by adults with many years of experience and full-time commitment to the sport. The gap between the United States and NJHS suggests that technological change has been biased. As far as records go, factors such as high-altitude training, daily massages, and years of sharpening matter a lot more than all-weather tracks and Nike footwear. This is only speculation, but it is testable.

We believe that our results and the methodology we apply have implications beyond athletics. The relative importance of globalization and of technical progress in explaining changes in North American and European income distributions has been a major topic of debate for close to a decade. Track and field records offer direct measures of both phenomena. In using athletic data to try to understand wider issues, we are following the tradition of Fellner (1969) and Barzel (1972).

We depart from Fellner and Barzel, however, in looking at the frequency of record breaks, and not actual performances. This approach offers two distinct advantages. Statistically, it lets us proceed nonparametrically without any strong assumptions about the underlying distribution of performances or the way in which that distribution is changing. More important, records are the natural way to look at discrete changes by optimizing agents. Kortum (1997), for instance, uses record theory to explain the issuance of patents. In addition to patents, economists are interested in how globalization and technological change affect a host of discrete decisions: how often workers move or lose their jobs, how often firms start up or shut down, how often comparative advantage in different products shifts, and how often new versions of software are introduced. For these questions, records are more relevant than performances.

II. Records and the Frequency of Change

A. *Standard Results*

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

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

We define e_t as the period t lower record indicator, a random variable that takes the value one if and only if a record is broken in period t: $e_t = 1$ if, for some r, $V_r = t$, and $e_t = 0$ otherwise.

The statistics literature contains two helpful results about record processes. For easy reference, we shall name them after their authors.

CHANDLER'S (1952) RESULT. The distribution of the lower record times (V_r)—and hence of the e_t—does not depend on the underlying distribution $F(\cdot)$ 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 two 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 shall talk simply of "records" without appending the designation of lower and upper.

The second consequence is that the frequency of change does not depend on the level of technology.[1] Since the distribution of record times does not depend on anything about $F(\cdot)$ (except continuity), it does not depend on the mean value of x. Years between record low temperatures in Bombay are distributed just as years between record low 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.

Chandler's Result highlights the importance of the assumption of an independent and identical distribution (i.i.d.) that the x_t are all drawn from the same distribution. Since the phenomena we are ultimately interested in—globalization and technological change—do not conform to the i.i.d. assumption, we shall ultimately have to drop it, but we shall do so in a manner calculated to preserve as many of these results as possible.

The next result pertains to record indicators.

RÉNYI'S (1962) RESULT. The record indicators $e_2, e_3, \ldots$ are independent Bernoulli variables with $\text{Prob}(e_t = 1) = 1/t$.

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 kth, is the minimum is the same as the probability that any other

[1] The distinction between the level that technology has achieved and the speed with which it is progressing is usefully made in discussions of technical progress by Jovanovic and Nyarko (1995) and Bartel and Sicherman (1999).

is the minimum. So the probability that the kth element in the sequence is the minimum is $1/t$. So the probability that x_t is the minimum and hence the probability that $e_t = 1$ is $1/t$. The argument for independence takes slightly more work, and so we omit it.

The immediate consequence of Rényi'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. 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.

B. 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. It can be thought of as an increase in the number of draws per period. Because of Chandler's Result, the standard formulas still hold if there are a large number of draws per period as long as that number is constant; the speed of change depends on the increase in the number of draws, not on its level. Fortunately, an increasing (or decreasing) number of draws can be fairly easily accommodated within the standard framework.

Let c_t, $t = 1, \ldots,$ be the number of draws in period t, and let $\lambda_t = \sum_{\tau=1}^{t} c_\tau$ denote the cumulative number of draws through the end of period t. Then think of a notional sequence with one draw 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 Rényi's Result, the probability that no record break will occur in period t of actual time is

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

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 draws to date, λ_t/t. Thus globalization can increase the speed of change if it adds draws fast enough.

We use the same framework to think about technical progress. Suppose for the moment that there is only one draw in every period and lower values are better (the draws might pertain to production cost, say). Let $F_t(\cdot)$ denote the distribution from which the draws are drawn in period t; technical change means that $F_t(\cdot)$ is no longer the same for every t. Technical *progress,* as opposed to just change, means that if $s > t$, $F_s(\cdot)$ is in some sense a better distribution than $F_t(\cdot)$. 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 shall 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 $\gamma(t, s) > 1$: 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 $F_s(\cdot)$ is the same as the distribution of the minimum of $\gamma(1, s)$ draws from the distribution $F_1(\cdot)$. So technical progress (as long as it is logarithmically proportional) is the same as globalization with $\gamma(1, s) = c_s/c_1$. If technical progress is being made, $\gamma(s - 1, s) > 1$, 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 draws, 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 that we are concerned with upper records and two periods. There are two cases. In case *A*, first-period draws are taken from a uniform distribution on the unit interval $U(0, 1)$ and second-period draws are taken from the distribution of the maximum of the two $U(0, 1)$ variables:

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

and

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

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

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

and

$$F_2^B(x) = [1 - \exp(-x)]^2.$$

Clearly, the speed of change is the same in both cases: the probability is $\frac{2}{3}$ that a record will be broken in period 2. But the rate of change in the mean is much different: the mean increases from $\frac{1}{2}$ to $\frac{2}{3}$ in case *A*, a gain of 33 percent, and the mean increases from 1 to $\frac{3}{2}$ in case *B*, a gain of 50 percent. So changes in expected performance are not the relevant focus in the study of the speed of discrete change.

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

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

we can reproduce all our previous results with starred variables.

III. 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, 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. We call the former international records and the latter local records. If the eligible population for a local record has been fairly constant, then only technical progress can increase the speed of change. The extent to which the speed of change in international records is greater than the speed of change in local records is a measure of the contribution of globalization to the total increase in the speed of change.

We have three series of international records—world (Hymans 1995), Olympic, and Millrose (Millrose Athletic Association 1996)—and two series of local records—United States (Davis and Carey 1983, 1991) and NJHS. Our starting dates range from 1877 for U.S. men's records to 1958 for NJHS records. Except for the Olympic games, which are held only every four years, we have annual data.[2]

A. *Nonparametric Estimates*

Our first step is to estimate the number of draws in each period—the $\{c_t\}$ sequence—for each of the five record data sets. To fix ideas, consider a sequence of observations of a large set of events that all have the same starting point. Let f_t, $t = 2, \ldots, T$, 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 $E_t = c_t/\lambda_t$. Thus f_t is an unbiased estimator of E_t. Consider the following estimates: $\hat{c}_1 := 1$ and

$$\hat{c}_t = \frac{f_t}{1 - f_t}\hat{\lambda}_{t-1},$$

where $\hat{\lambda}_{t-1} = \sum_{\tau=1}^{t-1} \hat{c}_\tau$. This implies $f_t = \hat{c}_t/\hat{\lambda}_t$.

Unfortunately, when different events start at different times and when events have breaks in competition—as they do in all our data sets—somewhat modified procedures are needed.[3] This requires maximizing a likelihood function. For several of our series, progress has been so great that estimated values of $\hat{c}_t$ became very large. Accordingly, without loss of generality, we write $\hat{c}_t = \exp \hat{\Gamma}_t$ and estimate the $\hat{\Gamma}_t$ noted.[4]

Figure 1 displays these nonparametric estimates of Γ for each of the five data sets.[5] We group four years as a single period and set $\Gamma = 10$ for the years 1959–62 as a baseline. Since the Olympics are held only every fours years, we set $\Gamma = 10$ for 1960.

The striking fact across all five data sets is the dramatic increase in

[2] A more detailed data appendix is available on request.

[3] These are discussed in our working paper (Munasinghe, O'Flaherty, and Danninger 1999).

[4] We thank the referee for this suggestion.

[5] The actual estimates and the corresponding standard errors are available on request.

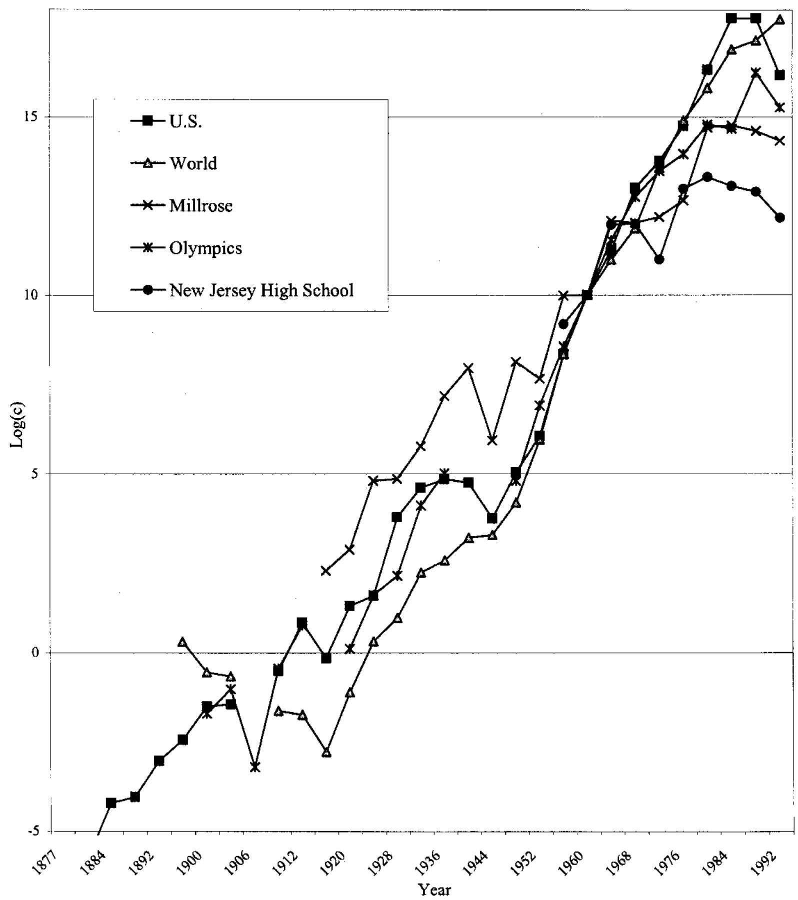

FIG. 1.—Progression of record breaks: nonparametric estimates of the log of implicit draws.

the progression of record breaks from our benchmark i.i.d. case. Our estimates of c_t increase at incredible rates considering that $\log(c_t)$ increases sharply over time (see fig. 1). The biggest improvements appear to occur during the 1950s and 1960s, and there is a slowing down during the 1980s and 1990s. Although the five series cannot be ranked unequivocally, the world and United States seem to grow fastest, with NJHS showing the least improvement.

TABLE 1
EXPONENTIAL ESTIMATES OF RECORD BREAK PROGRESSION: TIME TREND OF IMPLICIT NUMBER OF DRAWS

	World	United States	Olympics	Millrose	NJHS
Estimate of α	.260	.244	.203	.157	.053
Standard error	(.010)	(.010)	(.013)	(.015)	(.021)

B. Exponential Estimates

To put additional structure, summarize trends, and include other explanatory variables, we next employ 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 shall 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 $1-\exp(-\alpha) \simeq \alpha$, not zero. Continuing nontrivial proportions of record breaks are compatible with exponential growth.

For an event that began at time T,

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

which is the expression we estimate by maximum likelihood.[6]

We compute estimates of α for each of the five time series. They are presented in table 1. (We divide the estimate for the Olympics by four to be comparable with the other estimates since the Olympics are held every four years.) The estimates confirm some of our expectations. The underlying process for world records improves more quickly than the underlying process for U.S. records and the underlying process for NJHS records. Globalization increases the speed of change. Neither Olympic records nor Millrose records rise as quickly as world records. But note

[6] This framework allows us to easily handle discontinuities in the time series of events.

that the United States and many of its allies boycotted the 1980 Olympics, and the Soviet Union and its allies boycotted in 1984. And in the Millrose games, participation by the world's best athletes varies from year to year for a variety of reasons—publicity, prizes, and appearance fees.

But the difference between world and U.S. records is surprisingly small and statistically insignificant, whereas the difference between U.S. and NJHS 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 United States—does matter.

How big is the difference between the rates at which world and U.S. records are progressing? One way to answer this question is to think about the time lag between best world performances and best U.S. performances and to ask how long it would take for U.S. performances to catch up to world performances.

Specifically, we can compare the proportion of world records held by Americans in 1950 and 1995 and ask what year (before 1995) world performances would have to be frozen at in order to restore the proportion of American record holders to its 1950 level. We follow 27 common events for men and 11 events for women for which both world and American records are consistently available from 1950 to 1995. In 1950, with ties counted as fractions, Americans held 30.9 percent of these records. In 1995, Americans held 28.9 percent of these records. But if world performances had been frozen at their 1993 levels, Americans of 1995 would have maintained (or slightly exceeded) their 1950 proportion of world records. Thus, over 1950–95, technical progress alone (U.S. records) took 45 years to accomplish what technical progress and globalization together (world records) took 43 years to accomplish.

This actual progress is consistent with our estimated parameters in table 1. They imply that American performances of 1995 would hold 30.9 percent of world records of 1992, very close to the actual 1993 data.[7]

C. *Additional Explanatory Variables*

The exponential functional form we use to summarize trends also allows us to easily incorporate other explanatory variables into the estimation framework. We simply allow α to vary across specific events and years. Let

[7] We are grateful to an anonymous referee for suggesting this method of comparison.

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

for event i and time t, where X_{itj} is the value of the jth explanatory variable at time t and event j. Then from the appropriate analogue of (1) we can estimate the α_j^* and explain the rate at which the record process is changing.

There are a number of explanatory variables we consider, including gender and decade dummies. We expect world wars and boycotts of games, especially by major competing nations, to hurt performance. Hence we control for war years in our analysis of Millrose, U.S., and world records and for boycott years (1980 and 1984) in our analysis of Olympic records. For world records we also include an indicator variable for infrequently performed events since records are less likely to be broken for such events. Population growth (U.S. Department of Commerce 1993) and high school graduation growth rates in New Jersey public schools are included as proxies for domestic globalization in the U.S. and NJHS regressions, respectively.

A key variable we include across all specifications is hand timing. All our data sets have a common problem, especially for sprints, in the evolution of timing technology. At the turn of the century, timing devices were crude, coarse, and untrustworthy, and records were reported in fifths of a second. Accuracy increased over the next seven decades, and records came to be reported in tenths of a second. In the 1970s, electronic timing was initiated, and hundredths of a second became the currency. This improved accuracy still further.

How do these changes affect the rate at which records are being broken? Two forces work in different directions. First, 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. Second, decreases in measurement errors from year to year imply reductions in the variance of performances and, hence, a reduction in the rate at which records are broken. Thus timing improvements after 1910 should slow record progress, with a large one-time slowing at 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 sprints, but not in other events.

Table 2 presents labels and definitions of the explanatory variables. Table 3 presents regression estimates for world and U.S. records, and table 4 for Millrose, Olympics, and NJHS records.

These regression estimates do not noticeably change the conclusions from table 1. The reason for the relatively slow progress of NJHS record breaks (cols. 5 and 6 in table 4) is not that the series starts only in 1958; quite the contrary, periods of greatest growth for the world and the

TABLE 2
VARIABLE DEFINITIONS

Variable	Definition
Boycott	Dummy variable for 1980 and 1984 in Olympic games
Female	Women's events
Grad growth	Annual growth rate of graduating class from New Jersey public high schools
Hand timing	Running events ≤ 400 m during 1910–75, era of hand timing
Millrose HS	High school events in Millrose games
Rare events*	Events infrequently competed in for world records
Pop growth	Decade growth rates of the U.S. civilian population aged 20–35
World War I	World War I, 1914–18
World War II	World War II, 1939–45

* Rare events: 50 m, 80 m, 2 km, 3 km, 2 ml, 3 ml, 1 and 2 hours, 80 m and 200 m hurdles, 20 km, 30 km, 50 km, 3 × 800 m relay, 1,000 m and 1,200m relay, standing high/long jumps, and both hands shotput/discus/javelin.

United States occur after 1958. The major slowing down of NJHS records occurs during the 1980s and 1990s. The growth rate of graduation has a surprising negative sign, but it is insignificant (col. 6). Controlling for these factors raises the baseline record progression rate α to .245. This narrows the gap between NJHS and U.S. record break progression (especially in the 1970s) but does not eliminate it.

Several other variables performed as expected. Hand timing has the expected negative sign and is strongly significant across all five series. War is typically bad, and so are boycotts. Fewer records are broken in rare events in the world series (col. 2 of table 3). Women do better than men in the world (col. 2), but somewhat surprisingly, the difference is small in the United States (cols. 4 and 5). Further analysis showed, however, that almost all the female premium in the world record series is due to the "weight" events. Population growth for the U.S. series has the expected positive sign and is highly significant (col. 5).

To address the large disparity between NJHS and U.S. records, we look at retrospective data on New Jersey high schools for the 1919–58 period. The rate of progress does not appear appreciably greater for this period despite the large growth in high school enrollment.[8] As a final check we look at high school events in the Millrose games. From

[8] The details of this retrospective analysis including the results can be found in our working paper (Munasinghe et al. 1999).

TABLE 3
DETERMINANTS OF WORLD AND U.S. RECORD BREAK PROGRESSION

Variable	World (1)	World (2)	United States (3)	United States (4)	United States (5)
Omitted years	1886–1919	1886–1919	1877–1919	1877–1919	
Constant	−.453	−.679	.210	.258	.248
	(.102)	(.203)	(.023)	(.028)	(.019)
1920–29	.722	.961	.072	.025	
	(.107)	(.205)	(.042)	(.053)	
1930–39	.736	.979	.046	−.002	
	(.105)	(.204)	(.037)	(.034)	
1940–49	.636	.893	−.097	−.137	
	(.104)	(.204)	(.030)	(.042)	
1950–59	.885	1.115	.061	.014	
	(.107)	(.206)	(.037)	(.042)	
1960–69	.864	1.096	.294	.249	
	(.106)	(.205)	(.049)	(.053)	
1970–79	.849	1.070	.093	.054	
	(.107)	(.206)	(.040)	(.045)	
1980–89	.735	.943	.095	.061	
	(.105)	(.205)	(.039)	(.044)	
1990–94	.599	.835	−.122	−.163	
	(.105)	(.205)	(.042)	(.045)	
Hand timing	−.141	−.161	−.101	−.084	−.075
	(.023)	(.024)	(.022)	(.022)	(.021)
Female		.042		−.025	−.008
		(.022)		(.023)	(.027)
World War I		.390		−.198	−.219
		(.236)		(.047)	(.038)
World War II		−.039		−.022	−.169
		(.033)		(.035)	(.026)
Rare events		−.072			
		(.025)			
Pop growth					.273
					(.087)

NOTE.—Standard errors are in parentheses below the coefficient estimates.

the dummy variable on high school events in the Millrose regression in column 2 of table 4, we derive a rate of change quite similar to the NJHS rate. This further confirms large differences between high school and U.S. national records.

The time trend is not monotonic, and the 1980s and 1990s are in fact not outstanding. The best decade in the U.S. series is the 1960s, and the best decades in the world are the 1950s, 1960s, and 1970s. Our data do not support a faster change from any source since 1980.[9]

[9] Using data on performances in the Indianapolis 500, Barzel (1972) indirectly supports our contention of no speedup in change since 1970. On the basis of postwar data, he extrapolates a winning speed in the 2000 Indianapolis 500 of at least 203 mph. The actual win speed was 165 mph.

TABLE 4
Determinants of Millrose, Olympic, and NJHS Record Break Progression

	Millrose		Olympics*		New Jersey High Schools	
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Omitted years	1925–39	1925–39	1896–1929	1896–1929	1958–69	1958–69
Constant	.237	.245	.672	.671	.211	.245
	(.079)	(.057)	(.086)	(.106)	(.076)	(.080)
1930–39			.703	.686		
			(.251)	(.254)		
1940–49	−.125	−.137	−.085	−.097		
	(.090)	(.098)	(.181)	(.188)		
1950–59	−.042	−.026	.935	.897		
	(.086)	(.070)	(.262)	(.268)		
1960–69	.042	.081	.887	.847		
	(.085)	(.072)	(.202)	(.211)		
1970–79	−.119	−.118	.171	.128	−.021	−.064
	(.082)	(.064)	(.160)	(.172)	(.083)	(.086)
1980–89	−.005	.002	−.009	.200	−.210	−.286
	(.112)	(.077)	(.087)	(.240)	(.084)	(.093)
1990–94	−.229	−.232	−.454	−.465	−.240	−.341
	(.085)	(.071)	(.124)	(.138)	(.086)	(.103)
Hand timing	−.185	−.216	−.363	−.362	−.152	−.145
	(.049)	(.050)	(.129)	(.131)	(.091)	(.091)
Female		.047		.142		.082
		(.055)		(.133)		(.051)
World War II		.023				
		(.108)				
Millrose HS		−.150				
		(.047)				
Boycott				−.390		
				(.235)		
Grad growth						−.812
						(.531)

* Since Olympic events occur every four years, parameters should be divided by four for comparison.

IV. Applications to Economic Issues

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 interrecord times or turnover is distributed as a record break. Consider the following areas.

A. *Technical Progress and Globalization*

The relative importance of globalization and of technical progress in explaining changes in U.S. 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 technical progress. Track and field records offer such direct measures and let us evaluate the relative importance of technological progress and globalization.

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),[10] and there is no evidence to support the notion that limits are binding in either activity.[11]

Ideally, we would like to look at records for activities such as 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 with only a few elements 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.[12] For instance, one cannot improve performance in the long jump by using a raised takeoff board, placing a big fan behind oneself on the runway, or injecting copious amounts of steroids. Since most other areas of human endeavor do not operate under such restrictive rules, one might expect technical progress to be slower in track and field. On the other hand, the objective function in track and field

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

[11] 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).

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

is much simpler than the objective function in most other areas. A new type of car engine will be evaluated not only on 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 1,500-meter run, on the other hand, need produce only faster times. Technical progress might be faster in track and field for this reason.[13]

B. 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 compact discs became available. Abelard was true to his vows until Heloise came along. 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 U.S. 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 U.S. 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 the only areas in which switches are like record breaks. The theory of records offers testable predictions about how often people will change jobs, drugs, marriage partners, brands of soda, and political affiliations.

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[13] 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.

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