Structural Breaks in the Game: The Case of Major League Baseball

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Abstract: To search for eras in a sports league, we utilize time series tests with structural breaks to identify eras in Major League Baseball performance. Using data from 1871-2010, the mean and standard deviation of four different performance measures are examined to test if deterministic or stochastic trends and structural breaks are present. Throughout, we identify breaks endogenously from the data. Perhaps most notable among our findings, we identify a deterministic trend in the mean slugging percentage in 1921 and 1992, which coincides with the early years of the free swinging (Babe Ruth) era and the modern steroid era, respectively.

JEL Classifications: J24, Z2, C22

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1. Introduction

Over time, games change and new innovations are developed. In many sports the equipment drives these changes; such as innovations in tennis rackets, golf club technologies, or swim suits (now banned). In other sports change might result from the development of a new defensive technique (Lawrence Taylor), a new way to swing the bat (Babe Ruth), throw a pitch ("Bullet Joe" Bush), shoot a basket (Goose Tatum), or hold a putter (the current debate over the belly-putter). As players adopt successful innovations they are mimicked and the game can change.

Sports historians and scholars have often assumed *exogenous* changes in the game based on particular historical events. For instance, in baseball, one historian suggests that the game changed in 1920 when Ray Chapman was killed by a pitch that year and baseball responded by banning the spitball (Okrent, 1989). In contrast, we make no prior judgments about the timing of eras. Instead, we let the data speak to *endogenously* identify eras. To do so, we utilize time series tests with structural breaks to identify eras. Utilizing time series tests to analyze sports data has only recently become more popular in the literature and is most prominent in the works of Fort and Lee (2006, 2007), Lee and Fort (2005, 2008, 2012), and Mills and Fort (2014), who employ unit root and structural break tests to examine competitive balance in a number of sports.[1] In the present paper, we adopt a similar methodological approach and examine time series on the mean and standard deviation of four traditional Major League Baseball (MLB) performance measures. Our goal is to identify the timing of eras in MLB performance that may not have been apparent when focusing *a priori* on particular historical events.

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[1] See also the works of Scully (1995), Palacios-Huerta (2004), Schmidt and Berri (2004), and Nieswiadomy et al. (2012).

We find that most MLB performance measures are stationary around a deterministic trend with one or more structural breaks. Perhaps most notable among our findings, we identify a deterministic trend in the mean slugging percentage that shifts upward and changes slope in 1921 and 1992, which corresponds with the early years of the free swinging (Babe Ruth) era and the modern steroid era, respectively. We conclude that structural breaks should be considered when identifying eras and comparing performance over time. The paper proceeds as follows. The data and testing procedures are described in Section 2 and results in Section 3. We conclude in Section 4.

2. Data and Structural Breaks

MLB attracts the best baseball players in the world. The first professional baseball team was established in 1869 (the "Cincinnati Red Stockings") and the league itself started in the late 1800s (and continues today). The best players in the league have their names written in the record books. However, changes in the game have led to questions about how records should be kept. For example, Barry Bonds has the most homeruns in one season, 73 in 2001, while Babe Ruth hit 60 home runs in 1927. However, there were 162 games a season in 2001, but only 154 games in 1927 and some rules differed. While the number of homeruns per game is higher for Barry Bonds, differences in the game due to different technologies, rules, and style of play can matter.

Using data from Sean Lahman's Baseball Database on all MLB players from 1871-2010 with at least 100 at-bats, we measure slugging percentage (SLUG), home runs per hundred at bats (HR), batting average (BAVE), and runs batted in per hundred at bats (RBI).[2] With 35,728 single season observations we find that the average player hit 7

[2] Sean Lahman's Baseball Database: http://baseball1.com/2011/01/baseball-database-updated-2010/. Slugging percentage is calculated as total bases divided by the number of at-bats.

homeruns per season (with a maximum of 73), had 42.5 runs batted in (RBI), and a slugging percentage of .379. Using the data for each player, we calculate both the mean and standard deviation of each performance measure for each season. This provides annual time series from 1871-2010 that consist of 140 seasonal observations for each series. We utilize these eight time series in our empirical investigation. A summary of the mean and standard deviation of our data is provided in Table 1.[3]

To determine if the time series measures of player performance are stationary around a deterministic trend or non-stationary (stochastic trend) and to look for structural breaks, we begin by utilizing the two-break minimum LM unit root test proposed by Lee and Strazicich (2003).[4] To endogenously identify the location of two breaks ($\lambda_j = T_{Bj}/T$, j=1, 2), the minimum LM unit root test uses a grid search to determine the combination of breaks where the unit root test statistic is minimized (i.e., the most negative). Since critical values for the model with trend-break vary (somewhat) depending on the location of the breaks (λ_j), we employ critical values corresponding to the identified break points. Serial correlation is corrected by including lagged first-differenced terms selected by a sequential "general to specific" procedure.[5] The process is repeated for each combination

[3] We use only hitting statistics because of the length of the time series and because preliminary analysis on pitching statistics provided no structural breaks.
[4] By "structural break," we imply a significant, but infrequent, permanent change in the level and/or trend of a time series. See Enders (2010) for additional background discussion on structural breaks and unit root tests.
[5] To determine the number of lagged first-differenced terms that correct for serial correlation, we employ the following sequential "general to specific" procedure. At each combination of two break points over the time interval [.1T, .9T] (to eliminate end points) we begin with a maximum number of k = 8 lagged first-difference terms and examine the last term to see if its t-statistic is significantly different from zero at the 10% level (critical value of 1.645 in an asymptotic normal distribution). If insignificant, the k = 8 term is dropped and the model is re-estimated using k = 7 terms, etc., until the maximum lagged term is found (i.e., the order of serial correlation is identified and corrected), or k = 0 (i.e., there is no serial correlation). Once the maximum number of lagged terms is found, all lower lags remain in the unit root test. This type of procedure has

of two breaks to jointly identify the breaks and unit root test statistic where the unit root test statistic is minimized.[6] In each case, we begin by applying the two-break LM unit root test. If only one break is identified (at the 10% level of significance), we re-examine the series using the one-break LM unit root test (Lee and Strazicich, 2013). If no break is identified, we then utilize the conventional (no-break) augmented Dickey-Fuller unit test (Dickey and Fuller, 1979, 1981). Rejection of the null indicates that the series is stationary around a deterministic trend. In contrast, failure to reject the null implies a nonstationary series with a stochastic trend. [7]

After identifying the time series that are stationary around one or two breaks, we next perform tests to see if additional breaks are present. To do so, we utilize the multiple break tests suggested by Bai and Perron (1998, 2003, BP hereafter). Given that the BP tests are valid only for stationary time series, we begin by performing regressions on the level and trend breaks for the series identified as stationary with two breaks.[8] We then apply the BP test to the residuals of these regressions to search for additional breaks. Given that the breaks in these regressions are the same as those that reject the unit root hypothesis in the two-break LM unit root test, the residuals of these regressions will be stationary and the BP test can be safely applied to search for additional breaks.[9]

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been shown to perform well compared to other data-dependent procedures to select the optimal *k* and correct for serial correlation (e.g., Ng and Perron, 1995).

[6] Gauss codes for the one- and two-break minimum LM unit root test are available from the authors upon request.

[7] Note that the interpretation of breaks in a nonstationary (unit root) series differs from that in a stationary series. In a unit root process, a structural break in the level can be interpreted as an unusually large one-time shock or outlier, while a break in the trend can be interpreted as a permanent change in the drift.

[8] See Prodan (2008) for a discussion of pitfalls that can arise when applying the Bai and Perron (1998, 2003) type tests to nonstationary time series.

[9] See Lee and Fort (2005, 2008, 2012), Fort and Lee (2006, 2007), Bai and Perron (1998, 2003), and Lee and Strazicich (2003, 2013) for more detailed discussion of the tests described above.

3. Results

We begin by discussing the LM unit root test results displayed in Table 2. The slugging percentage mean (SLUGM) rejects the unit root null hypothesis at the 5% significance level in the two-break test, implying that SLUGM is a stationary series with structural breaks in 1921 and 1992. For the slugging percentage standard deviation (SLUGSD), only one break was significant in the two-break test. We therefore re-tested this series using the one-break test. In contrast to SLUGM, the SLUGSD cannot reject a unit root at the 10% level of significance, indicating that this series is nonstationary and has a stochastic trend. Similarly, the unit root hypothesis cannot be rejected for the homerun mean (HRM) at the 10% level of significance, implying that this series is nonstationary. In contrast, the unit root hypothesis is rejected for the homerun standard deviation (HRSD) at the 5% level of significance, indicating that this series is stationary with structural breaks in 1920 and 1966. The batting average mean (BAVEM) cannot reject the unit root hypothesis at the 10% level of significance, implying that BAVEM is a nonstationary series. In contrast, the batting average standard deviation (BAVESD) rejects the unit root hypothesis at the 1% level of significance, implying that BAVESD is a stationary series with breaks in 1906 and 1933. The runs batted in mean (RBIM) rejects the unit root hypothesis at the 10% level of significance, implying that RBIM is a stationary series with a break in 1887. The runs batted in standard deviation (RBISD) rejects the unit root hypothesis at the 5% level of significance, implying that RBISD is a stationary series with a break in 1921.

We next perform regressions on the level and trend breaks for the five performance measures that reject the unit root hypothesis in Table 2 (SLUGM, HRSD, BAVESD, RBIM, and RBISD).[10] The results are displayed in Table 3. White's robust standard errors are used to control for heteroskedasticity. Serial correlation is corrected by including lagged values of the dependent variable identified by a similar general to specific procedure as described in footnote 5.[11] In each case, Ljung-Box Q-statistics for 24 lags indicate that the null hypothesis of no remaining serial correlations cannot be rejected at the 10% level of significance. Using the residuals from the regressions with two breaks in Table 3, we then apply the multiple break BP test to SLUGM, HRSD, and BAVESD to search for additional breaks. A summary of the identified breaks is displayed in Table 4. Compared to the two breaks identified by the LM unit root test for SLUGM, HRSD, and BAVESD, the BP tests finds two additional breaks for each of these series. For SLUGM, the BP tests finds additional breaks in 1902 and 1920. Given that the break in 1920 is nearly identical to the break in 1921 identified by the LM unit root test, we will ignore this additional break in the discussion that follows. For HRSD, the BP test finds additional breaks in 1940 and 1945 during the period of World War II. For BAVESD, the BP tests finds additional breaks in 1879 and 1883.

To more carefully examine the sign and significance of including the additional breaks, we next perform regressions for the three series containing more than two breaks in Table 4 (i.e., SLUGM, HRSD, and BAVESD). Robust standard errors and lagged dependent variables are again included in each regression to control for heteroskedasticity and serial correlation. The results are reported in Table 5.[12] We begin

[10] Regressions will not be undertaken for SLUGSD, HRM, and BAVEM, since these series are nonstationary and spurious regressions can occur.

[11] See Ashley (2012) for discussion of why modeling serial correlation in regressions with lagged variables is a desirable procedure.

[12] As in Table 3, in each case the Ljung-Box Q-statistics for 24 lags indicate that the null hypothesis of no remaining serial correlations cannot be rejected at the 10% level of significance.

by discussing results for the slugging percentage mean (SLUGM). There is a downward shift in SLUGM in 1902, the additional break identified by the BP test, while the break coefficient is not statistically significant. Following this, there is a significant upward shift in the mean slugging percentage in 1921 and another upward shift in 1992. The break in 1921 coincides with the early years of the free swinging (Babe Ruth) era while 1992 coincides with the early years of the modern steroid era often associated with Jose Canseco and Mark McGwire, among others.[13] Following the upward shift in 1992, there is a small but significant downward trend in SLUGM.

We next examine regression results for the standard deviation of home runs (HRSD). Following the break in 1920, there is a significant upward shift in HRSD indicating that the dispersion in home run performance increased. Following this, there is a significant downward shift in 1940 followed by a significant upward shift in 1945. After the final break in 1966, there a significant downward shift in HRSD with a small but significant upward trend. Perhaps most notable among these findings is that we again see a significant structural break in 1920 associated with the early years of the free swinging (Babe Ruth) era. These findings provide additional support to the idea that the Babe Ruth era had a major influence on the game. During this time there were two major events: Babe Ruth influenced the game by creating a batting style that could be, and was, emulated by other players. Moreover, at the same time, the type of ball and style of pitching changed. We suggest that combined these changes had a significant impact on the game, which lead to a greater dispersion in home run performance among players.

[13] For example, in a statement released on the web site of the St. Louis Cardinals on January 11, 2010, Mark McGwire admitted using performance enhancing drugs beginning in 1989 or 1990.

We next examine the regression results for the batting average standard deviation (BAVESD). Following the break in 1879, there is a significant (at the 10% level) downward shift in BAVESD followed soon after by a significant upward shift in 1883. Following this there is a significant upward shift in 1906 and significant downward shift in 1933. After the final break in 1933, there is slight but significant downward trend in BAVESD.

Next, we examine results for the mean and standard deviation of runs batted in (RBIM and RBISD) using the single break regression results in Table 3. Following the break in 1887 there is an upward shift in RBIM. While there is a slight positive trend following the break, the trend slope is not significant (at the 10% level). For RBISD, following the break in 1921 there is an upward shift in RBISD. There is a slight negative trend following the break, but the trend slope is not significant (at the 10% level). While the break in RBISD is again associated with the Babe Ruth era, there is little notable change in the series before and after the break. Overall, the results for RBI suggest that there has been little change in RBIM and RBISD.

To better visualize the regression results of the stationary series with breaks reported in Table 5 (SLUGM, HRSD, and BAVESD) and Table 3 (RBIM and RBISD), we next construct simple plots of the estimated trends and actual data in Figures 1-5. As in the regression results described above, perhaps most interesting is the plot of the slugging percentage mean (SLUGM) displayed in Figure 1. From Figure 1, we can easily observe the significant upward shifts in SLUGM that occurred in 1921 and 1992, with the biggest upward shift apparent in 1921 during the early years of the Babe Ruth era. Similarly, in Figure 2, we see a notable upward shift in the standard deviation of home runs (HRSD) in 1920. In Figure 3, we can observe the general decline in the batting average standard deviation (BAVESD). In Figures 4 and 5, we observe the relative stability of the mean and standard deviation of runs batted in (RBIM and RBISD), respectively.

The above results suggest that MLB performance had a notable structural break around 1920-1921. The trend in the slugging percentage mean (SLUGM) had a positive upward shift in 1921 suggesting that the average player began to increasingly hit for power and hit more doubles, triples, and home runs. Similarly, the trend in the home run standard deviation (HRSD) had an upward shift and increasing slope in 1920 and the runs batted in standard deviation (RBISD) had a positive (small) upward shift in 1921. These findings suggest that players after 1920 became more diverse in their performance with some players increasingly hitting for power while others did not. Combined with the 1921 break in the slugging percentage mean (SLUGM), these findings suggest the possibility that following the success of Babe Ruth’s free swinging style, combined with the required pitching changes that occurred at this time, others that could mimicked his innovation and hit for power as well.

It is interesting to note that our *endogenous* stuctural break in 1921 occurs close to a historical break often identified by baseball historians. To provide historal context to this era Rothman (2012), a baseball historian, suggests that the 1920’s changed the offensive strategies in baseball due to three major events: The Black Sox scandal, the banning of the spitball, and Babe Ruth’s style of hitting being copied. The Black Sox scandal occurred in 1919 and caused the popularity of baseball to decline. Rothman further suggests that in an attempt to clean up the Black Sox scandal of 1919, the spitball and other trick pitches were abolished starting in 1920 (which also came after the death of Ray Chapman in 1920, for which "umpires were ordered to only use shiny white balls throughout the game"). Rothman further suggests that in 1919, when Babe Ruth hit a record 29 home runs during his last year with the Red Sox, that this created a notable increase in fan excitement about home runs. These events coincide with our suggestion that starting in 1920 and 1921 many players increasingly copied Babe Ruth's hitting style. This style included not choking up on the bat and swinging with a pronounced upper-cut. Ruth's style replaced the spray-hitting style that resulted in many singles. Rothman also notes that attendance in 1920 increased approximately 20% from 1919. As owners noticed this increase in attendance, they attribited this to an increase in offensive performance and home run hitting, which encouraged an increased adoption of this new style of hitting. We suggest that the structural break that we identify in 1921 is consistent with all three of the events described above; during, what most people remember as, the "Babe Ruth era."

Most notable among our other breaks is the significant upward shift in the slugging perecentage mean (SLUGM) found in 1992, which is closely associated with (what many preceive to be) the early years of the modern steriod era. Although it is difficult to identify the start of the steriod era since players attempt to keep hidden the use of performance enhancing drugs, it is interesting to note that while MLB banned steriods in 1991 they did not test for their useage until 2003. We suggest that fan interest in offensive performance (Ahn and Lee, 2014), coupled with the the knowledge that steriods were becoming an issue in MLB due to the explicit ban, might have caused the structrual break in 1992 as players mimicked steriod use knowing they would not be caught.

4. Conclusion

Over time, games change. Most analysts identify *exogenous* changes in the game based on particular historical events. In contrast, we utilize time series techniques to *endogenously* determine where changes occur. Using several time series on Major League Baseball performance from 1871-2010 (140 seasonal observations for each series), we attempt to determine if structural breaks can be used to define different eras.

Using several measures of batting performance, we perform time series tests to identify if deterministic or stochastic trends and structural breaks are present. Perhaps most notable among our findings, we identify significant structural breaks in 1921 and 1992 for the mean slugging percentage. Given that the breaks are endogenously determined from the data, it is interesting to analyze what was happening in the sport during these years.

Interestingly, the break in 1921 coincides with the early years of the free swinging era often identified with Babe Ruth. We suggest that during this time, other players began to mimic Babe Ruth's free-swinging style. In addition, pitching rules changed at this time. Combined, we suggest that these events had a major influence on baseball and changed the game. Finally, our identified structural break in 1992 is consistent with historical observations commonly associated with the early years of the modern steroid era. In particular, it is interesting to note that 1992 is one year after Major League Baseball enacted a ban on steroid use while the ban was not enforced with testing until 2003. In conclusion, we suggest that the findings presented here support utilizing time series tests with structural breaks to identify eras in sports and provide insights for future research.

References

Ahn, Seung C., and Lee, Young H. (2014). "Major League Baseball Attendance: Long-Term Analysis Using Factor Models," *Journal of Sports Economics* 15(5), 451-477.

Ashley, Richard A. (2012). *Fundamentals of Applied Econometrics*, Hoboken, NJ: John Wiley & Sons, Inc.

Bai, J. and P. Perron (1998). "Estimating and Testing Linear Models with Multiple Structural Changes," *Econometrica* 66, 47-78.

Bai, J. and P. Perron (2003). "Computation and Analysis of Multiple Structural Change Models," *Journal of Applied Econometrics* 18, 1-22.

Dickey, David A. and Wayne A. Fuller (1979). "Distribution of the Estimator for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association* 74 (366), 427-431.

Dickey, David A. and Wayne A. Fuller (1981). "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root." *Econometrica* 49, 1057-1072.

Enders, Walter (2010). *Applied Econometric Time Series*, 3rd edition. Hoboken, NJ: John Wiley & Sons, Inc.

Fort, Rodney and Young Hoon Lee (2006). "Stationarity and Major League Baseball Attendance Analysis," *Journal of Sports Economics* 7(4), 408–415.

Fort, Rodney and Young Hoon Lee (2007). "Structural Change, Competitive Balance, and the Rest of the Major Leagues," *Economic Inquiry* 45(3), 519-532.

Lee, Young Hoon, and Rodney Fort (2005). "Structural Change in Baseball's Competitive Balance: The Great Depression, Team Location, and Racial Integration," *Economic Inquiry* 43, 158-169.

Lee, Young Hoon, and Rodney Fort (2008). "Attendance and the Uncertainty-of-Outcome Hypothesis in Baseball," *Review of Industrial Organization* 33, 281-295.

Lee, Young Hoon, and Rodney Fort (2012). "Competitive Balance: Time Series Lessons from the English Premier League," *Scottish Journal of Political Economy* 59(3), 266-282.

Lee, J., and M. C. Strazicich (2003). "Minimum Lagrange Multiplier Unit Root Test with Two Structural Breaks," *Review of Economics and Statistics* 8(4), 1082-1089.

Lee, J., and M. C. Strazicich (2013). "Minimum LM Unit Root Test with One Structural Break," *Economics Bulletin* 33(4), 2483-2492.

Mills, Brian, and Rodney Fort (2014). "League-Level Attendance and Outcome Uncertainty in U.S. Pro Sports Leagues," *Economic Inquiry* 52(1), 205-218.

Nieswiadomy, M. L., M. C. Strazicich, and S. Clayton (2012). "Was There a Structural Break in Barry Bonds's Bat?" *Journal of Quantitative Analysis in Sports* 8(1), Pages –, ISSN (Online) 1559-0410, DOI: 10.1515/1559-0410.1305.

Ng, S., and P. Perron (1995). "Unit Root Tests in ARMA Models with Data-Dependent Methods for the Selection of the Truncation Lag," *Journal of the American Statistical Association*, 90(429), 269-281.

Okrent, Daniel (1989). *Baseball Anecdotes*. Oxford University Press.

Palacios-Huerta, Ignacio (2004). "Structural Changes during a Century of the World's Most Popular Sport," *Statistical Methods and Applications* 13, 241-258.

Prodan, Ruxandra (2008). "Potential Pitfalls in Determining Multiple Structural Changes With an Application to Purchasing Power Parity," *Journal of Business and Economic Statistics* 26(1), 50-65.

Rothman, Stanley (2012) Sandlot Stats: Learning Statistics with Baseball. The John Hopkins University Press.

Schmidt, M. B., and D. J. Berri (2004). "The Impact of Labor Strikes on Consumer Demand: An Application to Professional Sports," *American Economic Review*, 94, 344-357.

Scully, G. W. (1995). *The Market Structure of Sports*. Chicago: University of Chicago Press.

Table 1. Summary Statistics, Annual MLB Performance, 1871-2010

Variable	Mean	Median	Standard Deviation	Minimum	Maximum
SLUGM	0.372	0.377	0.034	0.302	0.433
SLUGSD	0.079	0.079	0.007	0.061	0.103
HRM	0.016	0.015	0.010	0.002	0.033
HRSD	0.013	0.015	0.006	0.003	0.022
BAVEM	0.263	0.262	0.014	0.230	0.304
BAVESD	0.040	0.038	0.006	0.030	0.057
RBIM	0.118	0.121	0.017	0.054	0.172
RBISD	0.041	0.041	0.005	0.031	0.062

Notes: Mean and standard deviation of annual Major League Baseball Slugging Percentage (Slugging Percentage is calculated by total bases divided by at-bats, SLUGM and SLUGSD), Home Runs (HRM and HRSD), Batting Average (Batting Average is calculated by hits divided by at-bats, BAVEM and BAVESD), and Runs Batted In (RBIM and RBISD), respectively. Data is calculated from Sean Lahman's Baseball Database on all players from 1871-2010 with at least 100 at-bats (http://baseball1.com/2011/01/baseball-database-updated-2010/).

Table 2. LM Unit Root Test Results, 1871-2010

Time Series	*Breaks*	*Test Statistic*	*Break Points*	*k*
SLUGM	1921, 1992	-5.714**	λ = (.4, .8)	0
SLUGSD	1904	-3.806	λ = (.2)	1
HRM	1949, 1975	-5.094	λ = (.6, .8)	0
HRSD	1920, 1966	-6.156**	λ = (.4, .6)	0
BAVEM	1891, 1941	-5.151	λ = (.2, .6)	6
BAVESD	1906, 1933	-7.344***	λ = (.2, .4)	0
RBIM	1887	-4.397*	λ = (.2)	8
RBISD	1921	-4.707**	λ = (.4)	5

Notes: SLUG, HR, BAVE, and RBI denote annual slugging percentage, homeruns, batting average, and runs batted in, where M denotes the mean and SD denotes the standard deviation, respectively. The Test Statistic tests the null hypothesis of a unit root, where rejection of the null implies a trend-break stationary series. *k* is the number of lagged first-differenced terms included to correct for serial correlation. The critical values for the one- and two-break LM unit root tests come from Lee and Strazicich (2003, 2013). The critical values depend on the location of the break points, $\lambda = (T_{B1}/T, T_{B2}/T)$, and are symmetric around λ and ($1-\lambda$). *, **, and *** denote significant at the 10%, 5%, and 1% levels, respectively.

Table 3. OLS Regression Results of SLUGM, HRSD, BAVESD, RBIM, and RBISD on the Level and Trend Breaks in Table 2, 1871-2010

$$SLUGM_t = 0.126 + 0.029D_{1922\text{-}92} + 0.046D_{1993\text{-}2010} + 0.0002T_{1871\text{-}1921} - 0.0001T_{1922\text{-}92} - 0.001T_{1993\text{-}2010} + lags(1) + e_t$$

(4.650)*** (3.800)*** (5.632)*** (1.471) (-1.336) (-2.178)**

Adjusted R-squared = 0.791 SER = 0.016 Q(24) = 30.321 (prob. value = 0.174)

$$HRSD_t = 0.002 + 0.004D_{1921\text{-}66} + 0.006D_{1967\text{-}2010} + 0.00003T_{1871\text{-}1920} + 0.0001T_{1921\text{-}66} + 0.00004T_{1967\text{-}2010} + lags(1) + e_t$$

(3.876)*** (5.009)*** (4.827)*** (1.967)* (3.142)*** (2.233)**

Adjusted R-squared = 0.947 SER = 0.001 Q(24) = 31.507 (prob. value = 0.140)

$$BAVESD_t = 0.051 - 0.006D_{1907\text{-}33} - 0.012D_{1934\text{-}2010} - 0.00003T_{1871\text{-}1906} - 0.0001T_{1907\text{-}33} - 0.0001T_{1934\text{-}2010} + lags(4) + e_t$$

(7.740)*** (-4.435)*** (-6.502)*** (-0.598) (-1.186) (-4.674)***

Adjusted R-squared = 0.875 SER = 0.002 Q(24) = 25.240 (prob. value = 0.393)

$$RBIM_t = 0.005 + 0.018D_{1888\text{-}2010} + 0.002T_{1871\text{-}87} + 0.00002T_{1888\text{-}2010} + lags(5) + e_t$$

(0.263) (1.245) (0.989) (0.688)

Adjusted R-squared = 0.639 SER = 0.010 Q(24) = 17.295 (prob. value = 0.836)

$$RBISD_t = 0.025 + 0.0005D_{1922\text{-}2010} - 0.00008T_{1871\text{-}1921} - 0.00002T_{1922\text{-}2010} + lags(4) + e_t$$

(2.930)*** (0.185) (-1.040) (-1.635)

Adjusted R-squared = 0.396 SER = 0.004 Q(24) = 14.026 (prob. value = 0.946)

Notes: Dependent variable is the slugging percentage mean, home runs standard deviation, batting average standard deviation, runs batted in mean, and runs batted in standard deviation, in year t, respectively. t-statistics are shown in parentheses. D and T represent dummy variables for the intercept and trend breaks identified using the LM unit root test as reported in Table 2. White's robust standard errors were utilized to control for heteroskedasticity. Lagged values of the dependent variable were included to correct for serial correlation using the method described in footnote 5. The Ljung-Box Q-statistic for 24 lags tests the null of no remaining serial correlations in the residuals. ***, **, and * denote significant at the 1%, 5%, and 10% levels, respectively.

Table 4. Summary of Structural Breaks in the Stationary Series, 1871-2010

Time Series	*LM Test Breaks*	*BP Test Breaks*
SLUGM	1921, 1992	1902, 1920
HRSD	1920, 1966	1940, 1945
BAVESD	1906, 1933	1879, 1883
RBIM	1887	-
RBISD	1921	-

Notes: SLUG, HR, BAVE, and RBI denote annual slugging percentage, homeruns, batting average, and runs batted in of all players in the series, where M denotes the mean and SD denotes the standard deviation, respectively. The LM Test Breaks are those identified with the Lee and Strazicich (2003, 2013) one- and two-break LM unit root tests. The BP Test Breaks are the breaks identified by applying the Bai and Perron (1998, 2003) procedure to the stationary residuals from the regressions on the level and trend breaks identified in the two-break LM unit root test.

Table 5. OLS Regression Results of SLUGM, HRSD, and BAVESD on the Level and Trend Breaks in Table 4, 1871-2010

$SLUGM_t$=0.147-0.010$D_{1903\text{-}21}$+0.038$D_{1922\text{-}92}$+0.057$D_{1993\text{-}2010}$+0.001$T_{1871\text{-}1902}$+0.002$T_{1903\text{-}21}$
(5.817)***(-1.235) (5.034)*** (7.072)*** (2.111)** (3.132)***

-0.0001$T_{1922\text{-}92}$-0.001$T_{1993\text{-}2010}$+lags(1)+e_t
(-1.612) (-2.002)**

Adjusted R-squared = 0.806 SER = 0.015 Q(24) = 29.077 (prob. value = 0.217)

$HRSD_t$=0.002+0.005$D_{1921\text{-}40}$+0.004$D_{1941\text{-}45}$+0.007$D_{1946\text{-}66}$+0.006$D_{1967\text{-}2010}$+0.00003$T_{1871\text{-}1920}$
(4.495)***(5.404)*** (2.732)*** (6.466)*** (5.451)*** (2.025)**

+0.0001$T_{1921\text{-}40}$+0.0002$T_{1941\text{-}45}$+0.00003$T_{1946\text{-}1966}$+0.00004$T_{1967\text{-}2010}$+lags(1)+e_t
(1.734)* (0.813) (0.832) (2.551)**

Adjusted R-squared = 0.950 SER = 0.001 Q(24) = 28.534 (prob. value = 0.238)

$BAVESD_t$=0.062-0.007$D_{1880\text{-}83}$-0.005$D_{1884\text{-}1906}$-0.011$D_{1907\text{-}33}$-0.018$D_{1934\text{-}2010}$-0.0002$T_{1871\text{-}1879}$
(6.983)***(-1.950)* (-1.266)*** (-2.778)*** (-4.004)*** (-0.398)

+0.0002$T_{1880\text{-}83}$+0.00003$T_{1884\text{-}1906}$-0.00008$T_{1907\text{-}33}$-0.00006$T_{1934\text{-}2010}$+lags(4)+e_t
(0.308) (0.529) (-1.476) (-5.086)***

Adjusted R-squared = 0.886 SER = 0.002 Q(24) = 28.478 (prob. value = 0.240)

Notes: Dependent variable is the slugging percentage mean, home runs standard deviation, and batting average standard deviation in year t, respectively. t-statistics are shown in parentheses. D and T represent dummy variables for the intercept and trend breaks reported in Table 4. White's robust standard errors were utilized to control for heteroskedasticity. Lagged values of the dependent variable were included to correct for serial correlation using the method described in footnote 5. The Ljung-Box Q-statistic for 24 lags tests the null of no remaining serial correlations in the residuals. ***, **, and * denote significant at the 1%, 5%, and 10% levels, respectively.

Figure 1. Slugging Percentage Mean, 1871-2010, and OLS Regression on Level and Trend Breaks in 1902, 1921, and 1992

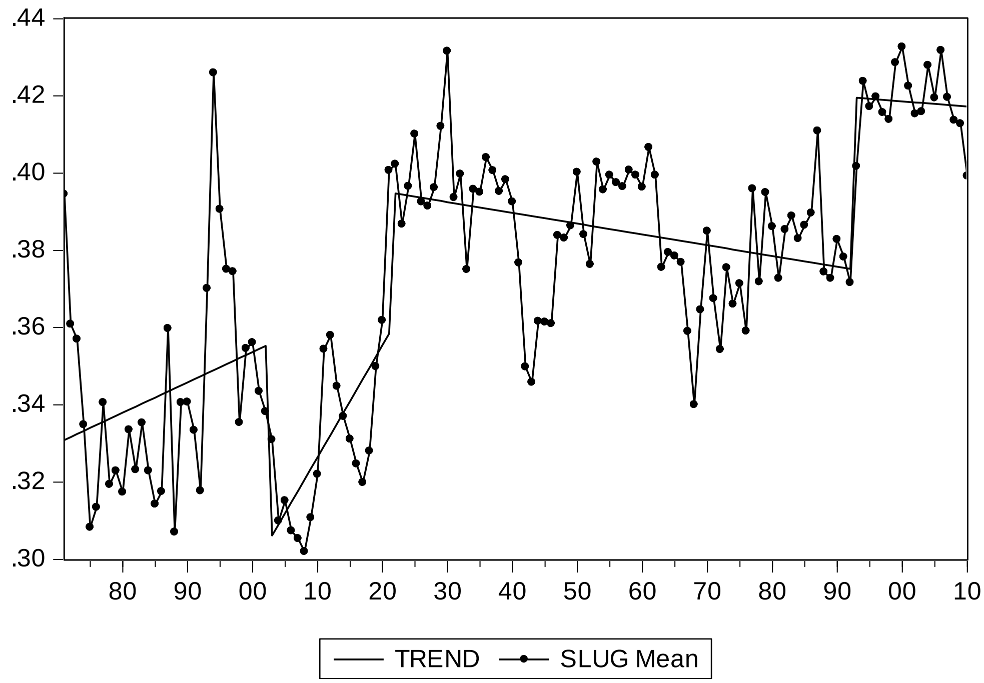

Figure 2. Home Run Standard Deviation, 1871-2010, and OLS Regression on Level and Trend Breaks in 1920, 1940, 1945, and 1966

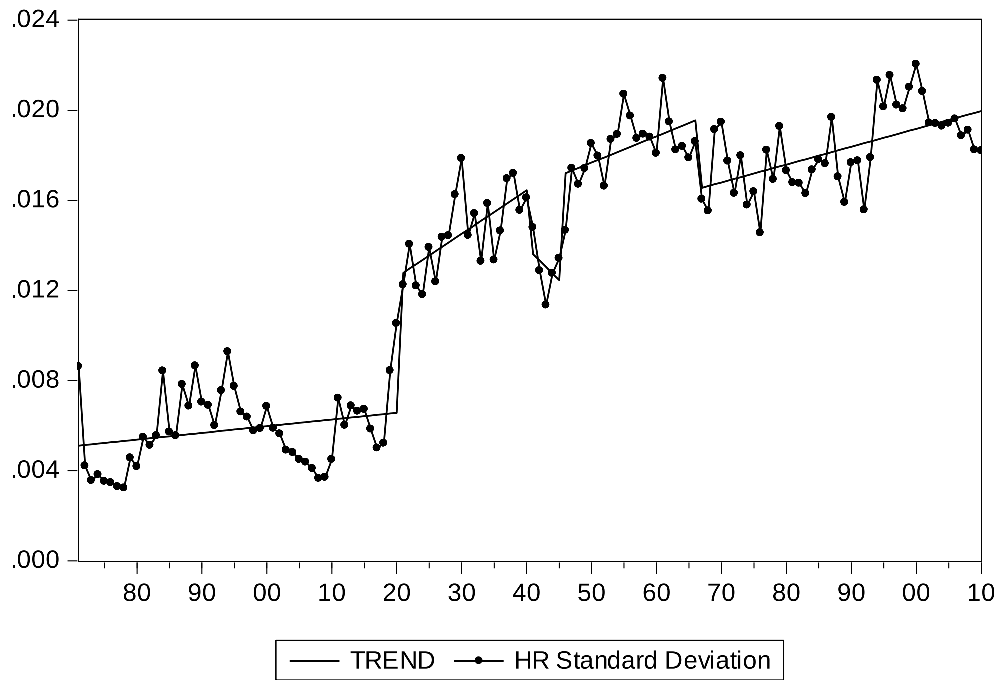

Figure 3. Batting Average Standard Deviations, 1871-2010, and OLS Regression on Level and Trend Breaks in 1879, 1883, 1906, and 1933

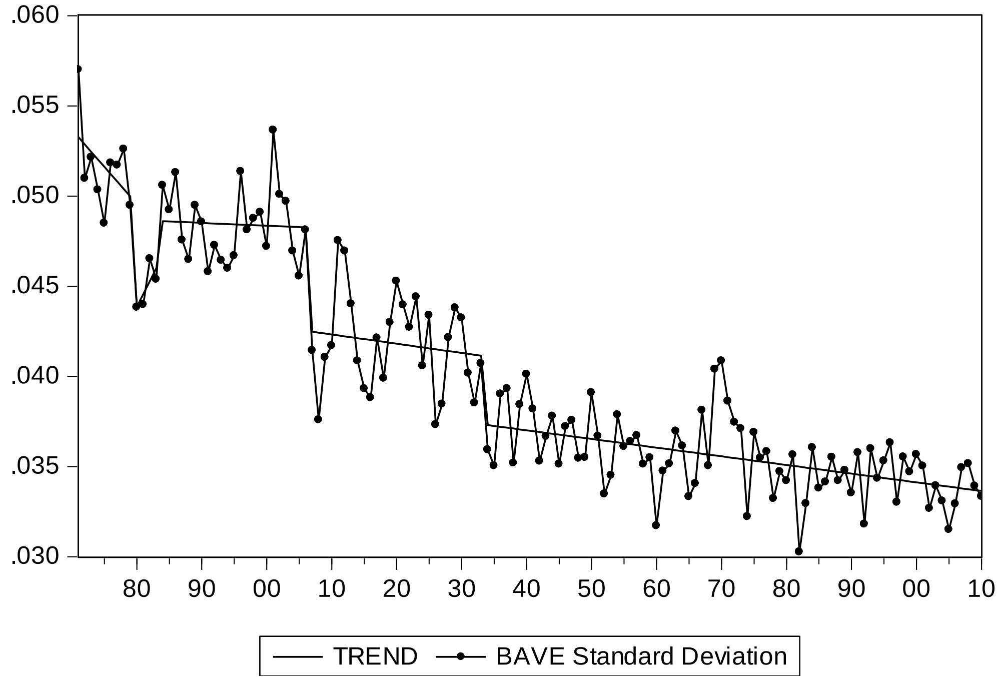

Figure 4. Runs Batted In Mean, 1871-2010, and OLS Regression on Level and Trend Break in 1887

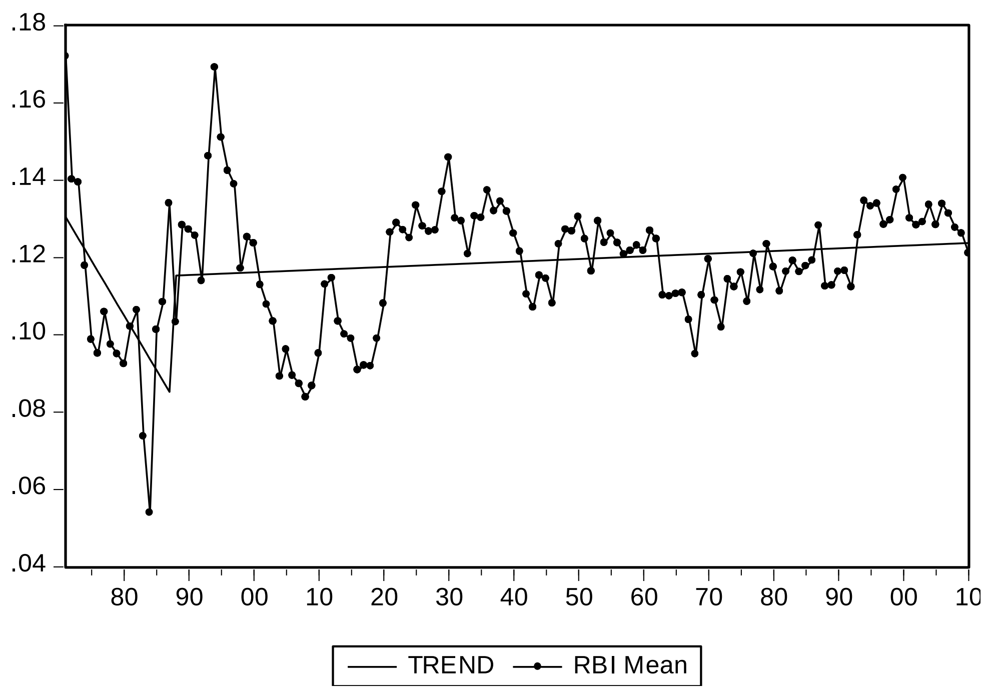

Figure 5. Runs Batted In Standard Deviation, 1871-2010, and OLS Regression on Level and Trend Break in 1921