Does Versatility Matter in Match-Play Sports?

Evidence from Sumo Wrestling

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Abstract In match-play sports, the best players seem to be both versatile and unpredictable in their use of techniques during play. Our analysis extends empirical work on player versatility and unpredictability to the Japanese sport of sumo wrestling. While earlier studies of tennis serves and football penalty kicks were motivated by game-theoretic analysis of choices made by players to start a match, our study is motivated by labor market theories that tie the success of workers to their portfolio of skills and its application to particular situations. We analyze panel data on tournament records of top sumo wrestlers participating in Japan's grand sumo tournaments over the 1995–2004 time period to test whether players with better physical attributes and a balanced, unpredictable portfolio of winning techniques are more likely to win matches. Our econometric results show that better physical attributes, a diverse portfolio of techniques to finish a match, and unpredictable use of techniques are all associated with more wins per tournament.

In match-play sports, the best players seem to be both versatile and unpredictable in their use of techniques during play. Even a casual fan of tennis watching a late-round match in the US Open can see that the best female and male players are about as comfortable making a winning shot with their forehand as their backhand. It's also easy for a fan to see some tennis players, known for blasting forehands and backhands, play several games when they use drop shots. Sometimes the player's strategy seems to be a best response to the opponent's choices within the play of a particular point or game but other times it seems to be done just to keep the opponent off guard for the rest of the match. So are versatility and unpredictability associated with wins in match play sports?

Previous empirical work on player versatility and unpredictability has been motivated by game-theoretic analysis of the strategies available to a tennis player serving to start a point or a football player taking a penalty kick (Walker and

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Wooders 2001; Walker et al. 2011; Chiaporri et al. 2003; Palacious-Huerta 2003).[1] All of these studies concluded that these players used *minimax* strategies involving versatile and unpredictable play.[2]

Our analysis extends empirical work on player versatility and volatility to the Japanese sport of sumo wrestling. One advantage of analyzing player choices in sumo is that it is a very simple game; two wrestlers face each other just once, with a match winner declared as soon as one wrestler hits the ground or steps outside the sumo ring. While earlier studies of tennis serves and football penalty kicks were motivated by game-theoretic analysis of choices made by players to start a match, our study is motivated by labor market theories that tie the success of workers to their portfolio of skills and its application to particular situations. We analyze panel data on the tournament records of top sumo wrestlers participating in Japan's grand sumo tournaments over the 1995–2004 time period to test whether players with better physical attributes and a balanced, unpredictable portfolio of winning techniques are more likely to win matches. Our econometric results show that better physical attributes, a diverse portfolio of techniques to finish a game, and an unpredictable use of techniques are all associated with more wins per tournament.

Brief Introduction to Sumo

Sumo is Japan's national sport. It is an ancient game that has changed little over the centuries. After engaging in ritualistic ceremonies, two wrestlers (*rikishi*) face each other in a crouching position in the middle of the *dohyō*, a ring (14.9 ft in diameter) built on straw rice bales with a surface of clay and sand. The first wrestler to step outside of the ring or touch the ground with any part of his body but the soles of his feet loses the match. Once this happens, a referee (*gyoji*) ends the match and indicates who the winner is. The referee's decision can be disputed and overruled by five judges (*shimpan*) who sit ringside. Usually a match lasts less than 30 seconds but can occasionally run for several minutes.

Japan is the only country with professional sumo wrestling. The Japan Sumo Association (*Nihon Sumō Kyōkai*—JSA) regulates the sport and organizes tournaments. All sumo wrestlers are affiliated with one of 40–50 "stables" (*heya*), where they live and train together.[3] Since 1992, the JSA has imposed official and unofficial limits on the number of foreign professional wrestlers, with each stable limited to

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[1] A penalty kick is essentially a single-play, match-play game inside the overall football game, as it matches one offensive player, the kicker, against one defensive player, the goalie, for a single play.

[2] In a two-person zero-sum game (such as a tennis point or a penalty kick in soccer or a sumo match), a minimax strategy is a mixed strategy in which each player acts to minimize the maximum payoff to the other player. Put another way, it involves the unpredictable use of multiple strategies.

[3] The JSA provides a guide to all *heya* at http://www.sumo.or.jp/en/sumo_data/sumo_beya/list. Accessed October 1, 2013.

one foreign wrestler since 2010. The JSA organizes wrestlers into six divisions, with the best wrestlers in the *Makuuchi* division (42 maximum), the next best in the *Juryo* division (28 maximum), and so on. Within the *Makuuchi* division, 21 wrestlers are assigned to an “East” Group and 21 to a “West” Group. There is an ascending hierarchy of wrestlers, from *Maegashira* to *Komusubi*, *Sekiwake*, *Ozeki*, and the grand champion, *Yokozuna*.

Competition takes place in six grand tournaments (*honbasho*), which are held in Tokyo in January, May, and September; in Osaka in March; in Nagoya in July; and in Fukuoka in November. During the 15-day tournament, wrestlers in the *Makuuchi* and *Juryo* divisions wrestle once every day, while those in lower divisions take part in just seven matches. Wrestlers face each other only once per tournament, and those in the West Group are always matched with wrestlers in the East Group.[4] At the start of the tournament, the JSA matches the lower ranked with the higher ranked players. As the tournament progresses, higher performing players are matched against each other to ensure the emergence of a tournament champion who has played the other top-performing wrestlers in the tournament.

After a tournament, JSA officials use the results to consider promoting high-performing wrestlers to a higher rank within their division or to a higher division. Wrestlers in the top two divisions who fail to achieve at least eight wins in a grand tournament face demotion to a lower division. The demotion rule has led to periodic scandals in the sport, as wrestlers with a 7–7 record have frequently transacted with their opponents to have them throw the 15th match, thereby avoiding a demotion. Duggan and Levitt (2002) analyzed data from the 1989–2000 period covering 32,000 matches involving 281 wrestlers in the top ranks and found convincing statistical evidence of match rigging involving wrestlers with 7–7 records on the final day of grand tournaments. A March 2011 police investigation of gambling by sumo wrestlers also produced convincing evidence of match rigging. The JSA subsequently expelled 23 wrestlers and initiated a number of reforms to clean up the sport (Hori and Iwamoto 2012).

Skills, Success, and Sumo

Wins in sumo derive from chance and each wrestler’s physical attributes and portfolio of sumo techniques.[5] If wrestlers had identical human capital, same bodies and same skills, then chance would determine the outcome of matches and tournaments. While such matches might be viewed as technically proficient, they might also become a little monotonous, even a little boring to the fan sitting in the 30th row of

[4] This rule ensures that wrestles from the same stable only compete against each other in a playoff to decide the tournament champion.

[5] Training for match play usually involves coaches, trainers, and training facilities. In sumo, the stable organizes the training and provides the additional facilities. Player motivation also determines number of wins in a tournament; we leave analysis of this factor for future research.

the sumo stadium who watches a parade of virtually identical athletes using similar techniques and strategies throughout a tournament. In fact, some of the fan interest in sumo and much of the strategy in a sumo match derives from the heterogeneity of the two wrestlers, each of whom exceeds the other on one or more human capital dimensions. Watching how a small agile wrestler with a great portfolio of techniques confronts a less agile but otherwise physically perfect wrestler or how a wrestler prolific in pushing techniques confronts a wrestler prolific in pulling techniques adds variety and interest to the sport. Taken to an extreme, heterogeneity is also likely to be less interesting to fans. If one wrestler has a strong absolute advantage over the others, then his starting move is his ending move, matches are short and uncompetitive, he quickly becomes a *yokozuna,* and many fans find little drama or interest in his matches.

The interesting case for both fans and econometricians is when two wrestlers start their match with a moderate degree of heterogeneity. Each might be slightly better in using some techniques and each have some more desirable physical attributes than his opponent. Given the simple structure of the game of sumo, one encounter and no accumulation of points within the match, we follow Walker et al. (2011) and assume that each wrestler chooses to play a minimax strategy as he opens play. We proceed tentatively by making the simplifying assumption that all sumo games ultimately proceed as either one-stage or two-stage games. Sumo is a one-stage game when a technique used by one player to start the match immediately catches the opposing wrestler off guard and that technique then becomes the officially declared winning technique.

What if opening parries do not produce an immediate advantage and the match proceeds further? Explicitly modeling play within a tennis point or a sumo bout has not been done to our knowledge so we proceed by simply assuming that a forced or unforced error by one player opens the door to an opportunity for the second wrestler to finish the match. If the player has a balanced portfolio of techniques available to him, he will have the appropriate technique available in his portfolio to finish the match.[6] If not, the other player's response will end the match in his favor. The situation is analogous to two tennis players who have evenly rallied back and forth within a point, until a forced or unforced error by one player leaves the other player with a "shot" opportunity to win the point, for example, to pass the player down the line. For a good player with a balanced portfolio of shots, it will not matter if the shot opportunity is to the player's backhand or forehand. When a good sumo player faces an analogous event, our expectation is that he will choose the appropriate technique from his portfolio and finish the match. Thus, among good sumo players, we expect to see versatility revealed in their use of winning techniques. Players who cannot execute commonly used basic techniques well, that is, they can push well but they cannot pull well, are less likely to finish the other player off when that technique is needed to end the match and they will win less often.

[6] In a tennis match, there are always some situations in which one particular shot, when well executed, is the potentially winning shot, and another will not suffice. An overhead smash of a lightly hit ball just over the player's head is one such example.

The JSA facilitates study of winning techniques in sumo because it records and publicizes the winning technique in each match. There are 80 official winning techniques. Only a few are observed regularly, and these are clearly and broadly defined as either pushing or pulling by JSA wrestling rules. The top two techniques, one of which belongs to pulling and the other to pushing, account for about half of total winning techniques, while the next four techniques account for about 20 % of the total. Following the JSA's official definition and categorization, this paper classifies all winning techniques into two groups, either pushing (*hanare* category) or pulling (*kumi* category).

As we describe in more detail below, wrestlers tend to use pushing and pulling as the winning techniques about equally. There is, however, sizable variation in the use of techniques among wrestlers, with some winning predominately by pushing and others by pulling. Their use of techniques also tends to change from tournament to tournament and over the course of their careers. This is because the competitive nature of the sumo world requires that wrestlers constantly train, learn new techniques, and become more proficient with ones they already know. This poses a big challenge for their opponents: What kind of techniques and strategies might they expect in the next match? To have the best chance of winning the match, an opponent needs updated information regarding the other wrestler's skills and his recent history in using these skills. Once this information is acquired comes a critical decision: How to translate the past information into beliefs about a wrestler's probable use of techniques and strategies in the next match?

Belief learning models developed in both the labor economics and behavioral game theory literatures have considered this problem in other contexts. In one class of models, interaction of dispersed initial beliefs and adaptive dynamics explains convergence in the pattern of player behavior over time. A popular model is weighted "fictitious play" (Cheung and Friedman 1997; Fudenberg and Levine 1998). In fictitious play, players keep track of the relative frequency with which another player has played each strategy in the past. These relative frequencies are then translated into beliefs about what the other players will do in the upcoming period. In the labor economics literature, Gibbons and Waldman (1999) and Gibbons et al. (2005) developed models of learning dynamics specifically for updating beliefs in a labor market. We apply a variant of their analysis to our problem and use it to motivate an econometric framework for analyzing wrestler's decision-making and performance.

Assume there are N players in a tournament and that each player should play a single match against all other players in a tournament.[7] Player i's winning ratio, P_{ijt}, at tournament t depends on the composition of opponents j. Player i has strength in a certain skill, θ_i, either pushing (θ_S) or pulling (θ_L). Neither skill can be directly observed. If player i plays against a group of opponents j at tournament t, L_{ijt}, the logistic transformation of the winning ratio is given by a linear model:

[7] In a sumo tournament, one player plays a second player only once, but not all players play each other due to the separation of players into East and West Groups and the large number of players (70) in the two top divisions.

$$L_{ijt} = \ln\left(\frac{P_{ijt}}{1-P_{ijt}}\right) = x_{it}\beta + z_i + c_{jt} + \gamma(\theta_{it} + \varepsilon_{ijt}) \qquad (1)$$

where x is a vector of player i's characteristics, z_i is the time-invariant unobserved portion of player i's ability which is equally valued amongst all players, c_{jt} measures the skill and composition of opponents j in tournament t, γ measures the return to player i's effective strength in certain techniques, and ε_{ijt} is a random error which is normally distributed.

We construct two specific variables for our purposes of analyzing sumo wrestlers' use of winning techniques. The first is a measure of belief in a wrestler's versatility in both techniques at time t, *Spread*. It is the difference between the individual's revealed use of a certain winning technique, $\bar{\phi}_{it}$, and the mean of winning techniques used by all players, $\bar{\phi}_t$, with $\bar{\phi}_t = \frac{1}{N}\sum_{i=1}^{N}\phi_{it}$. The values are calculated using information on the average frequency of winning with a technique, and an individual player's frequency of winning with the technique. *Spread* is high for a player who has a strong tendency to use a specific skill (either pushing or pulling) to win and low for a player without this tendency. If $\bar{\phi}_t = 0.5$, that is, if pushing and pulling are evenly used, then *Spread* is zero for a player who uses techniques evenly, and one for a player who specializes in only one skill. In our econometric analysis, we test whether *Spread* is negatively related to the probability of player i achieving a winning record in a tournament t.

The second measure is a common sample variance measure, $v_{it}^2 = \frac{1}{T-1}\sum_{k=1}^{T}(\phi_{itk} - \bar{\phi}_{it})^2$, where $\bar{\phi}_{it} = \frac{1}{T}\sum_{t=1}^{T-1}\phi_{it}$ and T is the time window used to measure the variance of winning techniques for each player. Being a squared quantity, v_{it}^2, the change in the degree of strength in a certain skill will be high when there is a big change in the combination of skills (pushing to pulling, and vice versa) used by a wrestler across tournaments. This measure, *Volatility*, is the degree of unpredictability of a wrestler's use of a certain technique to win the match. The obvious choice of T is 2; that is, the effect of unpredictability at time t depends only on how the player deviates from the last tournament ($v_{it}^2 = \frac{1}{2}(\phi_{it} - \phi_{it-1})^2$).[8] A longer history of the variance of skill use could also affect wrestler beliefs and probability of winning matches. Thus, we experiment with measures of *Volatility* that use $T=3$, 4, and 5.

Estimating Eq. (1) using ordinary least squares (OLS) yields biased estimates for x_{it}, *Spread*, and *Volatility* as the time-invariant player-specific effects (z_i) and the time-varying opponents-specific effects (c_{jt}) may be correlated with those variables. Use of fixed effects (FE) eliminates time-invariant player-specific effects, and

[8] Since $v_{it}^2 = [\phi_{it} - \frac{(\phi_{it} + \phi_{it-1})}{2}]^2 + [\phi_{it-1} - \frac{(\phi_{it} + \phi_{it-1})}{2}]^2$.

yields unbiased estimates if there is no change in the composition of opponents over time and no change in use of skills by their opponents ($c_{jt} = c_{jt-1}$). However, if these factors do change, then estimated coefficients from FE regressions will be biased. We leave this issue for future research.

Data and Variables

The data set consists of information on all sumo matches played by wrestlers in the top two divisions in the six official grand tournaments held each year between 1995 and 2004. It contains information on 25,156 matches played between 106 wrestlers. The average player appeared in 36 tournaments and played 478 matches over the 10-year period. Our econometric analysis uses the player's winning percentage in each tournament as the unit of analysis, and the data set contains 3,728 player-tournament observations. After dropping those wrestlers who have only short stints—less than 100 matches—in the top ranks, the final number of player-tournament observations falls to 3,012.

One interesting feature of sumo wrestling is that at the end of each match, a winning technique is determined by the judges and announced to the match's spectators.[9] Sumo wrestling rules clearly define more than 80 winning techniques.[10] The Japan Sumo Association also maintains a website with updated information on each player's winning techniques (*kamarite*) in recent tournaments.[11] We merge this information on winning (losing) techniques of each winner (loser) in each bout with the information on each player's profile provided by the Japan Sumo Association. Thus, the merged data set contains information on tournament results and information about wrestlers, including their history of winning techniques, date of birth, place of birth, date of debut, experience in sumo, tenure in rank, ethnicity, and body mass index (BMI). It is an unbalanced panel because some wrestlers either start or end their careers during our sample period.

We consider several control variables that may affect wrestler success. Physical condition is an important determinant of success for any athlete, and weight is particularly important for sumo wrestlers. Because there are no weight classes in sumo wrestling, an important part of a player's training regime is to add weight. However, too much weight may decrease an individual's agility and could result in diminished performance. Height is also an important determinant of performance in sumo because it enhances the overall stature of players. However, taller players are at a disadvantage in sumo wrestling because they have a high center of mass (balance point). This is why a wide and crouching stance is the chosen position

[9] It would also be useful to know which techniques each wrestler used to start the match and which techniques were used during the match but the JSA does not collect this information.

[10] See http://en.wikipedia.org/wiki/Kimarite. Accessed October 1, 2013.

[11] These are summarized in a pie chart on each player's JSA web page. For an example, see http://www.sumo.or.jp/en/sumo_data/rikishi/profile?id=2769. Accessed March 28, 2014.

before clashing with an opponent because a sumo wrestler makes himself as stable as possible with this stance. To control for these nonlinear relationships between height and weight, our regressions include a widely used summary statistic for weight and height, the BMI—defined as the ratio of weight (kilograms) to height squared (meters)—and BMI squared (BMI^2).[12]

Variables indicating years of experience (*Experience*) and years of tenure (*Tenure*) are also included as controls. *Experience* is calculated as the year in which the sumo tournament was played minus the year when the wrestler debuted. *Tenure* is the number of years of experience in the same rank. These variables, particularly *Tenure*, are possibly endogenous, but in our econometric analysis we treat them as exogenous.

Three dummy variables indicating the wrestler's country of origin are included in the model. A player's ethnicity may be related to his tournament performance if it serves as a proxy for player-specific heterogeneity. For example, the small statures of Mongolian players require them to resort to a wide variety of sudden moves and skills. The same is true for a few players from Hawaii whose stature ranks as amongst the largest in the pool of sumo players.[13] Being foreign born may also imply superior abilities, as the small group of foreign players may be the result of a selection process that allows only the best foreign players to participate in Japan's elite sumo tournaments. Amongst Japanese wrestlers, those originating from some regions could have an advantage based on tradition, culture, or regional support for sumo. Including dummy variables for players originating from Mongolia, Hawaii, and Tokyo allows us to partly control for this heterogeneity.

A dummy variable indicating that a wrestler could not finish all 15 bouts in a tournament is included in all regressions. Injury is the primary reason for a wrestler to withdraw, but wrestlers who had accumulated losses in eight matches were also more likely to leave a tournament. This is because wrestlers with more than eight losses already face demotion to a lower rank at the end of the tournament and have less incentive to play additional matches (Duggan and Levitt 2002; Dietl et al. 2010).

Results

Descriptive and Nonparametric Analysis

Table 1 presents descriptive statistics on sumo wrestlers' characteristics. Average height is 184 cm and weight is 155 kg. The minimum weight is 98 kg and the

[12] Our data set, which was provided by the Japan Sumo Association, contains a single measure of weight for each player. It is unknown when the weight was measured. Information on a player's weight for each tournament would be preferable, as player weight can vary over the course of a career. Since players tend to gain weight more rapidly early in their career, some of this change may be captured by the experience variable. Injury can also affect a player's success. Unfortunately our data set does not contain a measure of player injuries.

[13] The average height, weight, and BMI for Hawaiian players are 193 cm, 229 kg, and 61.5, respectively, while those for Mongolian players are 185 cm, 143 kg, and 41.6, respectively.

Table 1 Descriptive statistics for 106 sumo wrestlers, 1995–2004

Variables	Mean	SD
Height (cm)	184.14	5.45
Weight (kg)	155.51	24.36
Body mass index–BMI (weight/height^2)	45.79	6.34
Age at debut	18.50	3.20
Years of experience	9.62	5.13
Years of tenure	4.56	4.07
Hawaii origin	0.04	–
Mongolia origin	0.04	–
Tokyo origin	0.05	–
Number of matches	505.97	188.42
Number of matches won	257.26	105.99
Number of matches lost	248.71	100.37
Number of matches won by pushing	126.98	91.26
Number of matches lost by pushing	122.58	65.20
Percent of wins by pushing	0.48	0.24
Volatility (10^{-2})	0.01	0.82
Spread	0.38	0.37
Number of tournaments	36.00	12.60
Played less than 15 matches in a tournament	0.10	–

maximum is 275 kg. The average age at debut is 18.5 years, and average experience is 9.6 years. One wrestler debuted at age 15 and retired at age 42, recording the youngest age at debut and highest years of experience. About 4 % of wrestlers were from Hawaii, 4 % from Mongolia and other regions such as Russia, and 5 % from the Tokyo area. In 10 % of tournaments, at least one wrestler failed to complete all 15 bouts (307 dropouts in 3012 tournaments). Unreported regression results show that the hazard of a wrestler giving up on a tournament increased as it moved toward conclusion.

Wrestlers use both pushing and pulling techniques quite evenly in tournaments. Pulling accounts for about 52 % of winning techniques and pushing for 48 %. A binomial probability test cannot reject the hypothesis that the percentage of winning by pushing (or pulling) equals one half. There is, however, surprising variation amongst individual wrestlers in their use of these two techniques. For example, in one wrestler's 328 wins (out of 729 bouts), pushing is recorded as the winning technique 98 % of the time. In another wrestler's 195 wins (out of 401 bouts), pushing is recorded as the winning technique only 7 % of the time.

Figure 1 presents a kernel density distribution of player wins in matches with pushing listed as the winning technique.[14] A sign rank test strongly rejects the null hypothesis that there is no difference amongst individuals in their winning techniques.[15]

[14] Players who win by pushing often lose to an opponent who uses pushing as his winning technique. The correlation coefficients for each tournament are all positive, averaging 0.31.

[15] The z-value of the Wilcoxon sign-rank test is -10.29, which is statistically significant at the 1 % level.

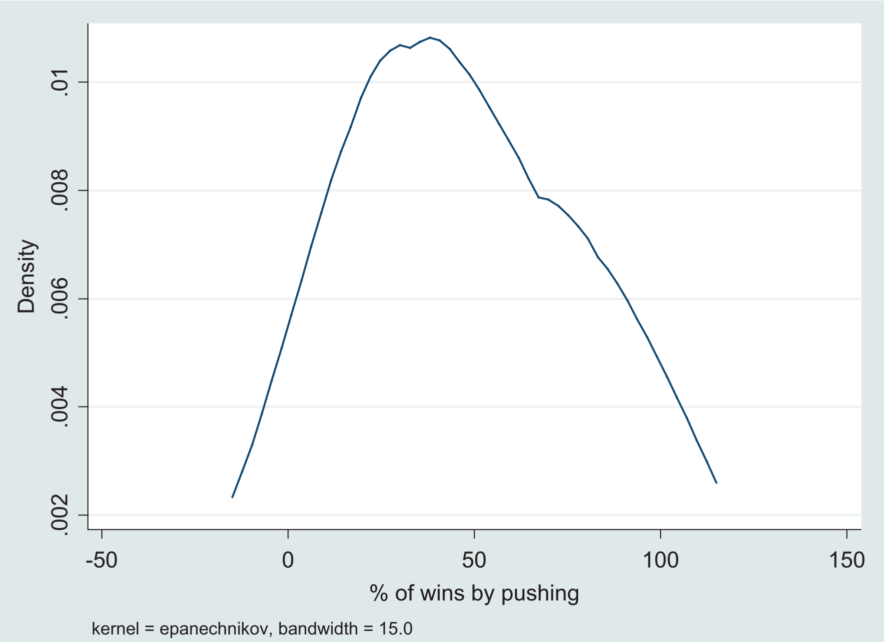

Fig. 1 Kernel density distribution of wins by pushing

Consider Fig. 2 which presents scatterplots and Lowess smoothed curves for the percent of wins achieved with the pushing technique for four selected wrestlers over 40+ tournaments. Figure 2a shows a wrestler whose use of winning techniques is quite volatile, displaying a wide dispersion of plots over time. Note that the percentage of wins achieved by pushing in tournament never exceeded 50 %, suggesting that he was a typical pulling wrestler. Figure 2b presents a wrestler who has a relatively low volatility around the Lowess smoothed curve and initially wins mostly by pulling. During his first 20 tournaments he shows a tendency to exhibit more versatility in choice of winning techniques but then, later in his career, he progressively uses pushing skills to win the match. Figure 2c portrays a wrestler with more volatility who exhibits a tendency over 12 tournaments toward pulling, followed by another period with a large swing toward pushing.[16]

Finally, Fig. 2d shows an extreme case, a wrestler with a winning technique of pushing in nearly every match that he won. Several other wrestlers also display the same pattern. None of these wrestlers are among the sport's top wrestlers, and

[16] Thus, for these players, strength in a certain skill might be conditionally dependent over time. The insight these wrestlers provide is that the process of skill use may exhibit serial correlation in the process or the persistence of volatility (*volatility clustering*), in which there are periods that display a wide swing for an extended time period. That is, for any given t, the random shocks of belief on strength in skills are conditionally independent but not identically distributed across players.

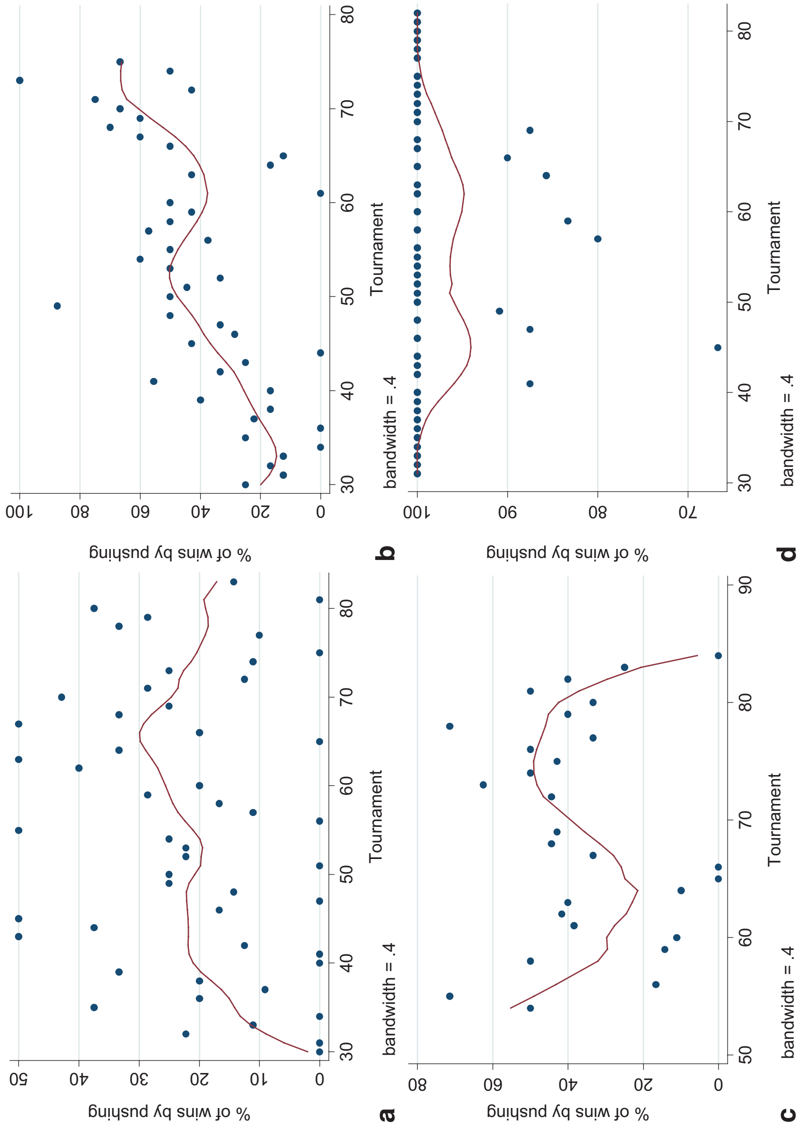

Fig. 2 **a** Percentage of wins by pushing (Wrestler A). **b** Percentage of wins by pushing (Wrestler B). **c** Percentage of wins by pushing (Wrestler C). **d** Percentage of wins by pushing (Wrestler D)

Table 2 Random effects and fixed effects estimates of $\ln\left(\frac{P_{ijt}}{1-P_{ijt}}\right)$, 1995–2004

	Random effects		Fixed effects	
BMI	0.081***	0.097***		
	(0.029)	(0.029)		
BMI²	−0.001***	−0.001***		
	(0.000)	(0.000)		
Experience	−0.031***	−0.032***	0.008	−0.118
	(0.008)	(0.008)	(0.046)	(0.352)
Tenure	0.018*	0.027***	−0.037	−0.037
	(0.010)	(0.010)	(0.047)	(0.047)
Hawaii	0.724***	0.713***		
	(0.183)	(0.176)		
Mongolia	0.105	0.143		
	(0.147)	(0.142)		
Tokyo	0.279**	0.288***		
	(0.123)	(0.118)		
Fewer than 15 matches	−0.197***	−0.197***	−0.201***	−0.205***
	(0.049)	(0.049)	(0.049)	(0.050)
Volatility	3.044*	2.762*	3.003*	2.913*
	(1.609)	(1.621)	(1.648)	(1.660)
Spread	−0.366***	−0.367***	−0.374***	−0.373***
	(0.037)	(0.037)	(0.038)	(0.038)
Year controls	No	Yes	No	Yes
R^2	0.116	0.121	–	–
Hausman test *p*-value				
Volatility			0.836	0.444
Spread			0.793	0.852
Number of observations	3012	3012	3012	3012

Volatility is measured only with respect to the previous tournament, i.e., $T=2$
*, **, and *** denotes statistical significance at 10%, 5%, and 1%, respectively

although they clearly have considerable skills in pushing, it appears as if they lack the portfolio of techniques required to win more consistently in the competitive world of sumo.

Regression Results

Our regression framework relates wrestler performance to their physical characteristics, their background, and their use of a balanced and volatile portfolio of sumo skills. Table 2 presents estimated coefficients from the random effects (RE) and fixed effects (FE) models. The dependent variable is a logistic transformation of a wrestler's winning ratio in each tournament.[17] Estimation is undertaken with and without year controls and using $T=2$ for *Volatility*. Including year controls leaves the signs of estimates unchanged but increases the magnitude of most estimates, with the notable exception of the *Volatility* estimates.

Estimated coefficients for most variables in the RE model are statistically significant, with the exception of the dummy for Mongolian origin. Those with high BMI are more likely to win matches, but the negative estimated coefficient on BMI^2 indicates diminishing returns to BMI. However, it should be interpreted with caution, as our data set contains a single measure of weight for each player, and player weight can change over the course of a career. The estimated coefficient on *Experience* is statistically significant and negative, suggesting that more experience leads to less tournament success. This may indicate an aging effect rather than skill accumulation; youth is often an advantage in physical contact sports. On the other hand, the estimated coefficient on *Tenure* is positive and statistically significant. However, the results for *Experience* and *Tenure* should also be interpreted with caution. In practice, duration in the same rank is determined by a player's winning rate, meaning that the tenure variable is endogenous. Wrestlers from Hawaii and Tokyo areas also tend to perform better. The estimated coefficient on the binary variable indicating drop-outs during a tournament is negative, as expected, and statistically significant.

Turning to our main results, the estimated coefficient on *Spread* is negative and statistically significant at the 1 % level under RE estimation, suggesting that the balance in winning techniques increases success of sumo wrestlers. Likewise, the estimated coefficient on *Volatility* is positive and statistically significant at the 10 % level, implying that winning games unpredictably increases wrestler wins. FE estimates for *Volatility* and *Spread* are quite similar to RE estimates in terms of both statistical significance and magnitude. Hausman tests cannot reject the null hypothesis that RE and FE estimates for *Volatility* and *Spread* are equal. We note that both *Experience* and *Tenure* lose their significance under FE estimation, suggesting that unobserved wrestler heterogeneity might be correlated with these two variables.

An important issue is whether our results are sensitive to the choice of time window (T) in the construction of the *Volatility* variable. To address this, we estimate the model using different time windows, assuming that all past events contribute equally to *Volatility*. Table 3 shows results for $T=3$, 4, 5, and 6. The results show that the estimated coefficients for *Volatility* are still statically significant for $T=4$ and 5 for RE estimates and marginally insignificant (12 % level) for FE estimates using the same time windows. *Volatility* is, however, never statistically significant when $T=3$ and when T = 6. The general pattern of results points to the wrestlers not looking back more than five tournaments when they construct their beliefs regarding the impact of volatile choices of techniques on their probability of winning a match.

[17] Substituting losing rates for winning rates would produce identical estimated coefficients with opposite signs.

Table 3 Random effects and fixed effects estimates of $\ln\left(\frac{P_{ijt}}{1-P_{ijt}}\right)$, 1995–2004: Time windows from three to six tournaments to measure volatility

A. Random effects estimates	$T=3$	$T=4$	$T=5$	$T=6$
Volatility	0.881	5.412*	5.920*	0.882
	(1.920)	(3.140)	(3.569)	(3.077)
Spread	−0.369***	−0.374***	−0.365***	−0.364***
	(0.037)	(0.038)	(0.037)	(0.040)
R^2	0.122	0.124	0.128	0.130
No. of observations	2917	2814	2714	2613
B. Fixed effects estimates	$T=3$	$T=4$	$T=5$	$T=6$
Volatility	0.669	5.170	5.694	0.315
	(1.978)	(3.254)	(3.730)	(3.202)
Spread	−0.375***	−0.381***	−0.371***	−0.370***
	(0.039)	(0.039)	(0.040)	(0.041)
No. of observations	2917	2814	2714	2613

All regressions include year dummies
*, **, and *** denote statistical significance at 10%, 5%, and 1%, respectively

To check the robustness of results, we estimate the regression model by adding interaction terms between BMI and *Experience*, with BMI^2 not included. These (unreported) results are interesting because the interaction term is negative and statistically significant at the 1% level, suggesting the effect of BMI decreases with age or experience. This change in specification has, however, little effect on other estimated coefficients.

In addition, we construct different measures of *Volatility* and *Spread* using different methods, namely using the top two most frequently used winning techniques or choosing the most and least frequently used winning techniques of each individual out of the top six most frequently used techniques in the population. We also estimated the model using a restricted sample in which only the first 3 years of tournament records for each player were included in the sample. Again, use of these alternative measures or a restricted sample leaves our main results with respect to *Spread* and *Volatility* qualitatively unchanged.

None of our regression specifications address potential endogeneity problems stemming from changes in the group of opponents over time or changes in opponents' use of techniques over time. This is left for future research.

Conclusion

Wrestler heterogeneity matters in sumo. Most sumo wrestlers do not have a perfect set of physical attributes and are more proficient in some sumo techniques than others. We used data from the Japan Sumo Association's six annual grand tournaments over a 10-year period to examine whether wrestlers with relatively balanced set of skills were more likely to be able to take advantage of opportunities in the course of play to finish off their opponent. Our results provide first evidence that an unpredictable use of a balanced set of winning techniques pays, yielding more wins for a wrestler. Ergo, versatility matters in sumo, and unpredictability matters too. Earlier studies of tennis and soccer showed that the best players used versatility and unpredictability in initiating their tennis serves and penalty kicks. Our study extends these results to decisions made by wrestlers to end a match. They point to the possibility that versatility and unpredictability may well be important in all phases of match play sports.

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