Do Skin Suits Increase Average Skating Speed?

Gerard H. Kuper and Elmer Sterken

Gerard H. Kuper (corresponding author)

Department of Economics, University of Groningen

PO Box 800, 9700 AV Groningen

The Netherlands

Tel +31 50 3633756

Fax +31 50 3637337

Gerard H. Kuper: g.h.kuper@eco.rug.nl

Elmer Sterken

Department of Economics, University of Groningen

PO Box 800, 9700 AV Groningen

The Netherlands

Tel: +31 50 3633723

Fax: +31 50 3637337

Acknowledgements: The authors thank Len Brownlie, Ruud Koning, and Rick MacDonald for suggestions and comments. Marcel Warnaar kindly provided us with data on individual skater rankings for the season 2000/2001 published by *The International Friends of Speed Skating*.

Abstract

We analyze the effectiveness of speedskating suits to increase average skating speed at the 2002 Olympic winter games of Salt Lake City. We model the average skating speed of male and female speed skaters at distances from 500 to 10000 meters. Speed not only depends on physical characteristics of the skaters, but also on previous performance and speedskating suits that reduce drag. We find that one specific suit, the so-called Swift Skin suit, significantly increases average skating speed, especially in long-distance events. This suits increase speed by up to 0.2-0.3 seconds per lap on a 400-meter oval. The effects are more pronounced for men than for women and show up in the first part of the race.

1. Introduction

The analysis of performance in sports events is complicated. Multiple factors, such as training, nutrition, individual athletic abilities (like maximum oxygen intake in endurance events or muscular strength in sprint events), and technical progress in equipment determine ultimate performance (see Atkinson and Nevill, 2001). This complicates identification of individual effects. In some cases one can use controlled experiments to single out specific determinants of performance. A disadvantage of experimental settings is that these settings do not provide a real competitive environment which mystifies the role of for instance mental factors. In this paper we use the best actual competition data one can obtain, namely Olympic results, to assess the impact of a special type of sports gear: a skin suit in speedskating events. As we will explain below, suits are nowadays of extreme importance for optimal performance in speedskating events. Our data include results of all speedskating events of the Salt Lake City Olympic winter games. We identify the impact of the suits of various brands on average skating speed using the heterogeneity in performance and abilities of different skaters.

Average skating speed is determined by the strength, endurance, and technical abilities of the skater, the quality of the skating ring, weather conditions, and aero-dynamics. Our paper contributes to a better understanding of the impact of suits on aerodynamics and through that average skating speed. Technical innovations are of extreme importance in speedskating. Here we first review the major innovations shortly. As far as technical innovations are concerned we can make a distinction between innovations of the ovals and the methods of ice preparation on the one hand and technical progress in speedskating gear on the other.

With respect to the innovations in ice skating ovals four major improvements took place in history. First, we discuss the construction of skating ovals at higher altitudes. Skating at a higher altitude is faster due to lower oxygen levels. On the one hand, at lower oxygen levels the body is stressed to become more efficient. On the other hand, there is less friction because of less dissolved oxygen in the ice. The oldest is the Davos oval founded at the end of the 19th century. The world's highest altitude oval is the Utah Olympic Oval in Salt Lake City (1305m): opened in 1995 and enclosed in 2000. A second innovation is the construction of refrigerated ovals providing a constant quality of the ice. The first one was opened in 1958 in Gothenburg. The third improvement is way in which ice is prepared. In the 1960s the ice in the Bislett stadium in Oslo was prepared with a spray of tiny droplets of water frozen in place which resulted in a smaller area of contact with the skate blade and thus less friction. Finally, a major improvement is the construction of indoor 400-meter ice rinks. Indoor rinks reduce wind drag. The first indoor ovals were developed in Heerenveen in 1986 and in 1987 in Calgary for the 1988 Olympic winter games. All these innovations are of influence on the development of average skating speed.

Secondly, we discuss briefly the progress of the technical quality of the skate. There is a steady growth in the technology of skates. Already at the end of the 19th century there was a technical innovation of the skates. Norwegian Paulsen introduced lighter metal tubes and longer and thinner blades without sacrificing the strength of the skate. We had to wait for a major innovation in skates until 1996 though. The Dutchman Van Ingen Schenau invented the klapskate: it disconnects the blade from the heel of the skate and has a pivot point under the ball of the foot allowing skaters to use the full extension of the leg to achieve maximum power and glide. The klapskate has contributed significantly to the progress in the development of world records in speedskating (see Kuper and Sterken, 2003).

The topic of this paper is the impact of another type of skating gear, namely skating clothes, on average skating speed. In 1976 skating clothes were innovated by the Swiss skating veteran Krienbühl, who introduced the tight-fit suits. At first, Krienbühl was not given the credits for a main innovation in speedskating, but in recent years his work has been acknowledged by skaters and by manufacturers of skating suits.. At the end of the previous century some skaters experimented with special sharkskin suits which are supposed to further, reduce the air resistance. For instance, just a few days before the start of the 1998 Olympic winter games of Nagano, Dutch speed skaters astounded their competitors by using zigzag stripes attached to their suits. The idea was that these stripes reduce drag and increase speed. After the 1998 Olympic winter games manufacturers started developing faster suits to further reduce drag and improve aerodynamics. Nike developed the Swift Skin suit that is an adapted version of the suit worn by track athletes Cathy Freeman and Marion Jones at the Olympic summer games of Sydney 2000. Actually, the motivation for Nike to develop tracks suits for the Sydney 2000 Olympic summer games came from speedskating. Competitive manufacturers of new skate suits are Mizuno, Descente and Hunter. Descente introduced the Vortex C2 suit and Hunter developed the Delta-Flash suit.

Because the decision to send athletes to the Olympic games is made by National Olympic Committees (NOC's) the choice for a certain suit is a national choice. The Australian, Dutch, and U.S. speed skaters and short trackers used Nike's Swift Skin suit at the 2002 Olympic winter games in Salt Lake City. Canadian competitors used the Vortex C2 suit and Norwegian skaters the Hunter Delta-Flash suit to give a few examples.

The new suits all share the same philosophy: a reduction of drag to increase skating speed. But do these suits really make a difference? According to Len Brownlie (Nike, 2002), an aerodynamics consultant to Nike Inc., the answer seems to be yes: "On average, skaters in the Nike Swift Skin performed almost 1% better than their previous personal records." Brownlie's estimate is based on the men's 500, 1000, 1500 and 5000 plus the women's 500, 1000, 1500 and 3000 meter races. His results show the average change in times between the skaters' Salt Lake performances and their previous Pre Salt Lake personal bests:

- Nike Swift Skin – US team athletes 0.91% faster
- Nike Swift Skin – Netherlands team athletes 0.93% faster
- Generic (non-branded) speedskating suits 0.05% faster
- The three other suits from major manufacturers all were slower, with negative percentages

These estimates are not completely informative though. The high altitude of the Salt Lake City Olympic Oval could be a determinant of the increase in performance.

In this paper we analyze the impact of the suits on average skating speed using the Salt Lake City 2002 speedskating results in more detail. We model the speed of male and female speed skaters at the various Olympic distances as a function of individual physical properties and other determinants such as the skating suits. In the next section, we briefly discuss the various suits. In Section 3 we present the data. Section 4 presents the statistical models and the results. We test the assumption that some manufacturer simply contracted the best skaters which could lead to overestimation of the impact of the suit on average skating speed. This assumption is carefully tested in Appendix A. Section 4 identifies the effect of the different suits on average skating speed. Section 4 also shows that this effect in particular shows up in the beginning of the race. Section 5 concludes.

2. Skating suits

Before we proceed in describing our data and presenting the analysis, we first describe the main attribute of interest, the new skating suits, in a little more detail. We include different brands of skating suits in our analysis: Nike, Descente, Hunter, Mizuno and non-branded (generic) suits. In the description of suits in this section we focus on the newly developed suits: (1) the Nike Swift Skin suit, (2) the Hunter Delta-Flash suit, and (3) the Descente Vortex C2 suit.

2.1 The Nike Swift Skin Suit

Nike is a leading sports gear manufacturer. A relative new Nike product, the Swift Skin Suit, is a head-to-skate aerodynamic speed suit. The developers placed six selected fabrics on certain body locations to work strategically and harmoniously with the skater's unique motion. This maximizes the performance output against the negative effect of air friction, as well other physiological and environmental factors. When possible, seams were aligned to correspond with the airflow direction or placed completely out of its way to further reduce drag. Where appropriate the Swift Skin was articulated to minimize creasing which could "trap" air and slow a skater. Additionally, low friction panels were placed under each arm and on the right inner-thigh to reduce body friction and further improve overall movement and human efficiency (up to 55% reduction in friction coefficients). The effect of the differently textured fabrics on the body is similar to the one that dimples have on a golf ball during flight. Velocity, physiology and size of each body segment dictate the texture and resulting textile.

The Swift Skin is available in two different versions, one for short track skaters and one for long trackers. Further, the long track version comes in three different models: sprint, middle distance and long distance. These models accommodate the vastly different needs of the varied distances that are contested in long track speedskating. The suit is completed with skate covers and gloves which work in conjunction with the Swift Skin.

2.2 The Hunter Delta-Flash Suit

Hunter Sportswear is a Dutch sports gear company. It sells the so-called Delta-Flash suit. This Delta-Flash suit developed out of the experimental strips the Dutch national team used at the Nagano 1998 Olympic winter games. The Norwegian speed-skating team used the Delta-Flash suit at the Olympic winter games in Salt Lake City 2002. The Dutch designers of the Delta-Flash suit had previously caused a rage in the skating world with their skate-strips, serrated strips of material attached to a skater’s head and lower legs. The strips definitely saved time during races, but most skaters didn’t position them optimally and thus they worked less effectively. Two years ago Hunter Sportswear asked the same designers of the University of Delft to incorporate the skate-stripe concept in a full-body skating suit design. The result is a suit with triangle-shaped thin rubber layers on the head and upper legs, attached to a smooth material. The arms and lower legs are made of coarse material, while the back and chest area also feature smooth material which is good for both aerodynamics and ventilation.

2.3 The Descente Vortex C2 suit

Descente is a Japanese firm by origin. It manufactures athletic, ski, and golf apparel mainly. In 1998, Descente started to develop new-technology ski suits resulting in the Vortex C1 model for the Salt Lake City Olympic winter games. Equally as innovative are Descente’s Vortex C2 speed-skating uniforms. They are designed to control and reduce turbulence through the use of silicon strips forming a spiral pattern around the thighs and lower arm. This so-called “Muscle Suit” is made from a red featherweight filmy fabric with iridescent shading around the muscle groups to make them stand out. The fabric in the new skin suits for 2002 is identical to the material used previously by the Canadian Skating Team in World Cup events. The main difference is in the application of specially placed spirals around the arms and legs. These spirals direct the flow of air over the suit in such a way that turbulence is reduced. Different shapes of spirals, different sizes and different placements were extensively tested and modified both in the field and analytically. The suit being introduced in January 2002 incorporates the most effective spiral pattern for speedskating and can give the athlete added stability and control. The suits also feature a pattern of raised silicone ribs to aid stability and turbulence control. Also, a new dimension of compression has been added to the suit to lower the total body area exposed to drag. The addition of the new ribs and the added compression of the suits reduce drag by an additional 5% over the contemporaneous suits.

****TABLE 1 NEAR HERE*****

There are no objective comparative analyses of these suits known. Therefore our analysis is the first to point out the differences between the various qualities. We do so by measuring the results in the world most competitive environment: the Olympic winter games. Table 1 gives a first impression: it shows that especially Nike has been extremely successful with its Swift Skin Suit in winning medals. This is no evidence of the relative out-performance of the Nike suit over the other suits though. It could have been that Nike has been able to contract the best skaters. We will illustrate this selection bias problem in Appendix A where we do not find compelling evidence that this has been the case.

3. Descriptive statistics

In order to test the impact of skating suits on average skating speed one would ideally want to have experimental data from aerodynamic analyses. These data are typically not available in a comparative setting. Individual producers tested the suits independently, but did not want to reveal the results. Moreover, in an experimental setting, one neglects the mental aspects of competition. This is the main reason why we proceed in using actual race data. In using the actual race data other problems arise. First, it is hard to combine various events, due to changes in weather, oval, shape of the skaters, and other conditions. So we used a single event: the Olympic winter games in Salt Lake City 2002. Secondly, it is the number of observations. One needs sufficient observations in each class (for each suit) in order to determine the significance of impact of the suits on average skating speed. We increase the number of observations used in estimation by modeling average skating speed for each lap. This implies that we do have multiple observations even for longer distances with fewer (16) competitors. For these long distances, the men's 10000 meters and women's 5000 meters, the number of observations for each type of suit though is rather low which implies that we should interpret the results with care.

Most of our data are collected from the official website of the nineteenth Olympic winter games in Salt Lake City from February 8 to 24, 2002: www.slc2002.org. We describe the data below. In the speedskating program ten events were scheduled. Speedskating is organized on a 400-meters oval. Two skaters compete in the same race and switch lanes each lap. Men skate 500, 1000, 1500, 5000, and 10000 meters and women 500, 1000, 1500, 3000, and 5000 meters. Table 2 gives an overview of the participation at events. Table 2 also gives the distribution of the skating suits used.

*****TABLE 2 NEAR HERE*****

The last columns shows the number of US speed skaters in all events, since we know from other research (see e.g. Balmer et al., 2001, Bray and Carron, 1993, Courneya and Carron, 1992) that the home advantage may help to explain athlete's performance. So, in estimating the models we control for the home effect. For all events we collected the lap-times of all skaters. We transformed these lap-times into average skating speed in meters per second. The highest average speed is obtained for the first full lap in the 1000 meters events (from 200 to 600 meter). The top speed here was 16.21 meters per second for men. But even the average speed in the last lap of the winner in the 5000 meters women event was 11.51 meters per second.

3.1. Individual physical characteristics

We collect data on the individual physical characteristics of the skaters: (1) ***AGE*** in years, (2), ***LENGTH*** in meters, (3) ***WEIGHT*** in kilograms, and (4) ***BMI***, or body mass index which equals weight in kilograms divided by the square of length in meters. Tables 3 and 4 give descriptive statistics of the data of interest.

*****TABLE 3 NEAR HERE*****

*****TABLE 4 NEAR HERE*****

We do not expect age of athletes to matter too much in the estimations of the model. NOC's select the best athletes available which makes average skating speed to be independent from age in our sample. Usually the top-athletes are neither very young nor very old. In our data set all speed skaters are aged between 17 and 35. But we do take ***AGE*** into account in modeling average skating speed, because it is well known that over lifetime performance varies (see Fair, 1994, and Sterken, 2003). The body mass index might matter across distances. In general, sprinters have stronger muscles and hence are heavier if compared to long distance speed skaters. However, again sample selection may play a role here.

3.2 Performance indicators of athletes

Next we need to have indicators of the quality of the skaters in terms of results prior to the Olympic winter games. In order to assess the impact of skating suits we need to be sure that we condition the model of average skating speed on the individual quality of the competitors. For each competitor we have the seasonal best speed (***SBS***) in meters per second on the event, the personal best speed (***PBS***) in meters per second, and the ratio of these two speeds which we define as an index for potential performance: ***POT***=***SBS/PBS***. The seasonal best performance may be a good predictor for performance at the Olympic winter games. If, for whatever reason, the personal best is better than the seasonal best (i.e. ***SBS/PBS***<1), then performance at the Olympic winter games nevertheless may be good because the athlete has performed well in the recent past: experience also matters.

For longer distances speed fluctuations during the race might be of influence. If a skater is able to maintain a fairly constant speed during a race (a so-called flat scheme) the end result will be optimal (see also e.g. Keller, 1974). A low coefficient of variation (standard deviation of speed divided by the average speed during the race) indicates a flat scheme. We will use the variable ***FLAT*** (the coefficient of variation of the average lap speeds) to measure this so-called long distance-ability. See Tables 3 and 4 for a description of the data.

3.3 Gear and other factors

Finally we have some 'facts' data: the brand of the skating suit a speed-skater used in the race (all dummy variables), the home advantage dummy variable (being ***HOME***=1 if the skater was a U.S. citizen) and the lane at opening (***LANE***=1 if the lane of opening was the inner lane). The latter variable could be of influence on the shorter distances. The lane matters especially for the 500 meters. That is why the 500 meters event is raced twice. If a skater in the first race starts in the inner lane, then in the second race he will start in the outer lane.

As is indicated in the introduction the quality of the skating ring and weather conditions also influence average skating speed. These factors are excluded from our analysis because these factors are the same for all competitors. The same holds true for the klapskate since every skater uses these skates nowadays.

4. The model and the estimation results

The main focus of our paper is on the impact of wearing a skin suit on average skating speed. In order to estimate the impact of a suit on average skating speed we need two things: a model of average skating speed and sufficient data to be able to test the model. What are the determinants of skating speed on a certain distance? Since we can assume that racing conditions were identical for all competitors in the Olympic events, we can concentrate on individual effects.

In general, age will affect average speed (see Fair, 1994 for a model of athletic events and age effects). But here we can assume that the NOC's have selected their best skaters and age effects will be not over-important (we will check this statement below). Secondly, of course the distance matters (see e.g. Francis, 1943). We will estimate separate models for separate events which implies that the distance is identical for all skaters in the model to be estimated. So we will use individual skater characteristics to explain the average skating speed.

In sprint events, like the 500 and 1000 meters, we expect that skaters with a higher body mass index (***BMI***) will perform better: sprinters have relatively strong and heavy muscles. It might be argued that there is an optimal body mass and optimal age. As is argued above, NOC's selection procedures take account of this. The penalty on deviations from optimal age and body mass is already reflected in the selection of our sample. So in principle we would have to use a nonlinear 'penalty' function, but selection allows us to enter ***AGE*** and ***BMI*** linearly in the model. Because of selection strategies of NOC's, we do not expect age and body mass to be important determinants of speed (we will check this statement). Alternative estimations (not shown here, but available from the authors) with quadratic age and body mass, penalizing deviations from optimal age and body mass, do not change the results to a large extent. In long-distance events, like the 5000 and 10000 meters, we expect that skaters who are able to produce a flat schedule (so a low coefficient of variation of lap-speeds ***FLAT***) will perform better.

4.1. The model

We model average skating speed of the various events using a pooled linear regression model. The dependent variable is average speed (in meters per second) of athlete *j* in lap *i*, denoted as $\boldsymbol{SPEED_{ij}}$. For the 500 meters event, *i*=100, 500. For the men's 10000 meters, *i*=400, 800, …, 10000. We estimate speed for all five events and for men and women separately, because the events differ by nature. The shorter distances are anaerobic events, while especially the 5000 and 10000 meters are aerobic events, focused on maximum oxygen intake capabilities. Throughout this paper we estimate the models with the fixed-effects estimator and apply cross section weights. The cross-section units are laps *i*.

The factors discussed in the previous section are used as explanatory variables, Note that these factors are fixed across the cross-section units (laps *i*). The model that is estimated for each of the events is:

$$\begin{aligned} \boldsymbol{SPEED_{ij}} = {} & \alpha_1\, \boldsymbol{AGE_j} + \alpha_2\, \boldsymbol{BMI_j} + \beta_1\, \boldsymbol{SBS_j} + \beta_2\, \boldsymbol{POT_j} + \beta_3\, \boldsymbol{FLAT_j} + \\ & \gamma_1\, \boldsymbol{HOME_j} + \gamma_2\, \boldsymbol{LANE_j} + \gamma_3\, (\boldsymbol{NIKE_j - GENE_j}) + \gamma_4\, (\boldsymbol{HUNT_j - GENE_j}) \\ & + \gamma_5\, (\boldsymbol{DESC_j - GENE_j}) + \gamma_6\, (\boldsymbol{MIZU_j - GENE_j}) + \boldsymbol{\delta_i} + \boldsymbol{e_{ij}} \end{aligned} \qquad (1)$$

where $\boldsymbol{\delta_i}$ are the fixed effects (different intercepts across laps *i*) and $\boldsymbol{e_{ij}}$ is a white noise residual. We lump length and weight in the Body Mass Index ***BMI***. For the sprint events β_3 is assumed to be 0 (***FLAT*** is considered to be important in long-distance racing events), whereas for the long distances γ_2=0 (the choice of the lane is unimportant).

The dummy-variables for the suits are ***NIKE***, ***HUNT*** (for Hunter), ***DESC*** (for Descente), ***MIZU*** (for Mizuno), and ***GENE*** (generic). We assume that these dummies are exogenous. In other words the selection of skaters by the various suit manufacturers is independent of performance. The model is a fixed-effects model. That is it includes a cross-section specific constant instead of a common constant. That is the reason why the suits dummies enter the model compared to the generic suit. Including all suit-dummies separately in the fixed-effects model violates the assumption of independency of the regressors since all dummies add up to one. Dropping one dummy makes the estimation results sensitive to which suit-dummy is removed. This unfavorable outcome is avoided by including suit-dummies relative to a "benchmark-suit". Now the outcomes are not sensitive to the choice of benchmark-suit. We choose the generic suit as benchmark, except for the Women's 5000 meters event. For this event we used Mizuno as benchmark, because the only female using a generic suit did not finish.

4.2. The estimation results

We present the results of the estimation of Equation (1) in Tables 5 and 6. For the women events $\boldsymbol{HUNT_j}$ **-** $\boldsymbol{GENE_j}$ is excluded from the regressions since Norway did not send female skaters to the Salt Lake City Olympic winter games (see also Table 2). Furthermore, the regressions exclude fallen skaters and skaters who were either disqualified or did not finish.

*****TABLE 5 NEAR HERE*****

*****TABLE 6 NEAR HERE*****

Tables 5 and 6 reveal the following. First, both ***AGE*** and the body mass index ***BMI*** do not explain consistently average skating speed. ***BMI*** is only important for the 1000 meters average skating speed for men and for women's 1500 meters average skating speed. In general, *AGE* is unimportant which hints at the optimal selection by NOC's. The seasonal best performance in terms of speed (***SBS***) is a very powerful explanatory variable for all events (except in the 10000 meters event for men) for both men and women. Men's 10000 meters is a very demanding event which is not skated very frequently during the skating season. Also past performance, measured via ***POT***, is important for most events, especially for men. For distances of 3000 meters and more the ability to maintain more or less constant speed is also a very important determinant of speed. If ***FLAT*** increases, the average lap speeds fluctuate and average overall speed drops.

The home advantage is only found to be important in the men's 5000 meters event. Starting in the inner lane has a significant (only at 10%) impact on the 500 meters result for men. Maintaining a high speed in the second curve is sometimes a problem for the inner lane skater (who started in the outside lane and switches to the inner lane after 250 meters). For men starting in the inner lane, lane advantage yields an increase in speed of 0.05 meters per second. This would imply almost 0.1 second on the total race time which is a substantial amount on the 500 meters racing time. For the 1000 meters for men and both 500 and 1000 meters for women there is no lane effect.

*****TABLE 7 NEAR HERE*****

*****TABLE 8 NEAR HERE*****

The main focus of our paper is the effect of the suits on speed. Tables 7 and 8 summarize the effect of the suits on average speed. The effect of the benchmark suit, in all but one case the generic suit, is calculated as minus one times the sum of the coefficients on the other suits. For men we find a significant positive contribution to skating speed of the Nike suit for most distances. For women we find a significant positive contribution of the Nike suit for the longer distances (1500 meters and more). The generic suit contributes to speed in two out of ten distances: men’s 5000 meters and women’s 500 meters. For the other suits we do not find any positive contribution. For some distances we find a rather surprisingly negative effect. The Descente Vortex C2 suit has a negative effect on the men’s 10000 meters event and the women’s 5000 meters event. Mizuno contributes negatively to speed for men’s 1500 meters and 10000 meters events and women’s 3000 meters. However, some of these results might be due to the low number of observations (Hunter and Descente) and should not be given too much attention.

What do our results imply? First of all, the suits seem to help the best in the medium- and long-run distances. For the 500 meters event, it is the strength and skating ability that determine average speed. For women's events also the medium- and long-run distances benefit from the Nike Swift Skin Suit. The suits do not have an impact on the average skating speed of women in sprint events. In terms of speed there is a substantial increase of about 0.2 meters per second if the skater wears the Nike suit. This is more than 1 per cent of average skating speed which can be labeled to be substantial. For instance on the 1500 meters event this implied a reduction of the skating time by more than 1 second. The bronze medal winner Sondral (and defending Olympic champion) was the first non-NIKE suit skater, who might have been adversely affected. According to our model Sondral could have skated a time of 1 minute 43.82 seconds (instead of 1.45.26) which would have been faster then the winning time of 1.43.95 by Parra.

4.3. The effect of the Nike suit during the race

The new skate suits are designed to reduce drag. As is show above, the Nike suit effectively does reduce drag and increases speed. These results apply to the average speed. The problem of drag especially occurs when the skater is able to maintain an ideal low skating position and keeps his or her body stable. However, as the race progresses it is becoming increasingly difficult to keep the body in a stable low position. As a consequence drag reduction will effectively increase speed in the early stages of the race. The Nike-parameter in the models is allowed to be cross-section (i.e. lap) specific. The estimation results are not shown; instead Figures 1 and 2 show the parameter estimates and the 95% confidence interval per lap for all ten distances. In seven events the Nike suit on average increases speed and in these events the gain is in the first part of the races. In three events, for instance the men's 5000 meters, Nike did not increase speed on average and also there is no significant effect during the race, neither positively nor negatively.

****FIGURE 1 NEAR HERE****

****FIGURE 2 NEAR HERE****

5. Conclusion

In this paper we construct a model of average skating speed to analyze the effectiveness of the speedskating suits specially developed for the 2002 Olympic winter games of Salt Lake City. We model average skating speed as a function of individual skaters' characteristics like age, length, and weight, of pre-event performance (personal and season's best speeds), home advantage, starting lane, and the skating suits. We conclude that individual body characteristics do not matter (which seems to be logical given selection of athletes by NOC's), pre-event scores do matter, the home advantage is rather unimportant, while only the Nike Swift Skin suit contributes to higher average skating speed. The Nike suit increases speed by up to 0.2-0.3 seconds per lap which is substantial and decisive in events like the Olympic winter games. We also show that in races in which the Nike suit is effective, the gain is made in the first part of the race. Apparently, speed skaters are only able to benefit from the ideal working of the suit in the beginning of a race, because they are able to position their body optimally to reduce drag. Speedskating therefore benefits to a large extent from technical innovations.

References

Atkinson, G. and Nevill, A.M. (2001). Selected issues in the design and analysis of sport performance research. Journal of Sports Sciences, 19, 811-827.

Balmer, N.J., Nevill, A.M. and Williams, A.M. (2001). Home advantage in the winter Olympics (1908-1998). Journal of Sports Sciences, 19, 129-139.

Bernard, A.B. and Busse, M.R. (2000). Who wins the Olympic games: economic development and medal totals. Yale School of Organization and Management, mimeo.

Bray, S.R. and Carron, A.V. (1993). Home advantage in alpine skiing. Australian Journal of Science and Medicine Sport, 25, 76-81.

Courneya, K.S. and Carron, A.V. (1992). Home advantage in sport competitions: A literature review. Journal of Sport and Exercise Psychology, 14, 13-27.

Fair, R.C. (1994). How fast do old men slow down? Review of Economics and Statistics, 76, 103-118.

Francis, A.W. (1943). Running records. Science, 98, 315-316.

Keller, J.B. (1974). Optimal velocity in a race. American Mathematics Monthly, 81, 474-480.

Kuper, G.H. and Sterken, E. (2003). Endurance in speedskating: development of world records. European Journal of Operations Research, 148, 2, 293-301.

Nike (2002). Statistics show Nike swift skin winning the speedskating race. http://www.nike.com/nikebiz/news/pressrelease.jhtml?year=2002&month=02&letter=i. Press release, Kearns, Utah, February 23, 2002

Sterken, E. (2003). From the cradle to the grave: How fast can we run? Journal of Sports Sciences, 21, 6, 179-191.

Appendix A: Selection

Our results show that the Swift Skin suit really makes a difference. But is it the suit that matters or did Nike contract the best athletes? In other words, is there a selection bias in the model, such that our Nike-dummy variable is not a true exogenous variable in our skate speed model, but a variable that is determined by other variables not included? To answer this question we estimated binary choice or logit models in explaining the Nike dummy variable using rankings for the season 2000/2001. We take these old rankings as true exogenous variables that could have been a guideline for Nike to contract (national teams) of skaters:

$$\boldsymbol{NIKE_j} = \alpha + \beta\, \boldsymbol{RANK_j} + \boldsymbol{e_j} \qquad (2)$$

where the dependent variable is a dummy variable which takes on value 1 if skater *j* wears the Nike suit and value 0 otherwise. The explanatory variable *RANK* is the individual ranking for the season 2000/2001 published by *The International Friends of Speedskating* (http://home-1.tiscali.nl/~knmg2168/ifs/ranking/). Nike also sponsors short-track skaters, so we also collected short-track data. For short track we used the team rankings for the season 2000/2001 from the ISU scoreboard (http://204.57.46.141/interlynx/). For both events, we use the rankings for the season 2000/2001 to make sure that the results are not affected by the fact that some skaters already used the Swift Skin suit before the Olympic winter games of 2002. Nevertheless, we also tried the 2001/2002 rankings (not shown here because the results were not affected).

****TABLE 9 NEAR HERE****

The estimation results for Equation (2) are in Table 9. For speedskating Nike did not pick the athletes completely randomly. The higher the position of the ranking (i.e. the lower the rank number) the higher the probability that the skater wears Nike's Swift Skin suit. However, if we use the personal best performance or seasonal best performance instead of the IFS rankings, we did not find any significant results, so it seems questionable that Nike indeed selected top performers alone. For short track we only have very few observations. Here the ranking does not help to explain the Nike dummy. The same result applies if we use the team rankings for season 2001/2002. In all cases, however, the statistical fit is very poor. So, there is no strong statistical evidence that Nike simply contracted the best skaters. May be it is money that matters. After the 2000 Olympic summer games in Sydney, Nike explores any sport that races against the clock, not just running. The fact that the last editions of the Olympic games where held in Australia and the United States may explain why these countries are partners in the project with Nike. The cooperation between Nike and the Dutch team seems to be guided by the Dutch ongoing quest for innovative apparel, like the klapskate, in speedskating. Our conclusion however is that our assumption of the exogenous dummy variable for Nike holds which renders our estimation of the average skating speed adequate.

Table 1. Results of suit manufacturers at the Salt Lake City 2002 Olympic winter games

	Event	Nike	Descente	Hunter	Mizuno
Men	500m	1^{st}, 3^{rd}			2^{nd}
	1000m	1^{st}, 2^{nd}, 3^{rd}			
	1500m	1^{st}, 2^{nd}		3^{rd}	
	5000m	1^{st}, 2^{nd}			3^{rd}
	10000m	1^{st}, 2^{nd}		3^{rd}	
Women	500m		1^{st}		2^{nd}, 3^{rd}
	1000m	1^{st}, 3^{rd}			2^{nd}
	1500m	3^{rd}			1^{st}, 2^{nd}
	3000m	2^{nd}	3^{rd}		1^{st}
	5000m	2^{nd}	3^{rd}		1^{st}

Table 2. Participants at the Salt Lake City 2002 Olympic winter games

			Participants wearing					
	Event	Total	Nike	Hunter	Descente	Mizuno	Generic	Home
Men	500m	38	8	1	4	13	12	4
	1000m	44	8	3	4	14	15	4
	1500m	48	8	3	4	15	18	4
	5000m	32	6	3	3	9	11	3
	10000m	16	5	2	1	5	3	2
Women	500m	31	7	0	2	16	6	4
	1000m	36	8	0	3	18	7	4
	1500m	39	8	0	3	18	10	4
	3000m	32	6	0	3	14	9	3
	5000m	16	5	0	3	7	1	2

Table 3. Characteristics of male competitors per event

Event	Variable	Obs.	Min	Max	Mean	Std.dev
500m	Age (years)	76	17	34	25.92	3.91
	Length (meters)	72	1.62	1.93	1.80	0.07
	Weight (kilograms)	72	63	96	80.17	7.02
	Body mass index (kg/m^2)	72	19.88	27.43	24.68	1.57
	Seasonal best speed (m/s)	76	13.47	14.46	14.14	0.24
	Personal best speed (m/s)	76	13.47	14.57	14.17	0.25
1000m	Age (years)	44	17	34	25.36	3.98
	Length (meters)	42	1.69	1.93	1.81	0.06
	Weight (kilograms)	42	63	95	80.02	6.54
	Body mass index (kg/m^2)	42	19.88	26.83	24.30	1.52
	Seasonal best speed (m/s)	43	13.49	14.77	14.26	0.37
	Personal best speed (m/s)	43	13.52	14.77	14.31	0.34
1500m	Age (years)	48	17	35	25.13	4.29
	Length (meters)	46	1.63	1.91	1.81	0.06
	Weight (kilograms)	46	63	95	78.17	7.28
	Body mass index (kg/m^2)	46	19.88	26.32	23.72	1.59
	Seasonal best speed (m/s)	48	12.96	14.18	13.75	0.31
	Personal best speed (m/s)	48	13.20	14.26	13.86	0.27
5000m	Age (years)	32	18	34	26.53	4.13
	Length (meters)	31	1.63	1.99	1.80	0.07
	Weight (kilograms)	31	63	92	76.45	6.64
	Body mass index (kg/m^2)	31	20.68	25.64	23.52	1.27
	Seasonal best speed (m/s)	32	12.25	12.96	12.62	0.17
	Personal best speed (m/s)	32	12.37	13.17	12.77	0.21
10000m	Age (years)	16	23	34	28.25	3.70
	Length (meters)	16	1.63	1.90	1.78	0.08
	Weight (kilograms)	16	63	86	76	7.27
	Body mass index (kg/m^2)	16	20.68	25.64	23.95	1.16
	Seasonal best speed (m/s)	16	11.95	12.43	12.15	0.15
	Personal best speed (m/s)	16	11.97	12.76	12.34	0.21

Table 4. Characteristics of female competitors per event

Event	Variable	Obs	Min	Max	Mean	Std.dev
500m	Age (years)	62	18	35	26.26	4.24
	Length (meters)	58	1.58	1.80	1.68	0.05
	Weight (kilograms)	58	53	75	63.21	4.82
	Body mass index (kg/m^2)	58	20.42	25.51	22.47	1.18
	Seasonal best speed (m/s)	62	12.27	13.43	12.97	0.27
	Personal best speed (m/s)	62	12.39	13.43	13.00	0.25
1000m	Age (years)	36	20	35	25.92	3.86
	Length (meters)	34	1.58	1.80	1.68	0.05
	Weight (kilograms)	34	53	75	62.76	4.38
	Body mass index (kg/m^2)	34	20.42	25.51	22.19	1.04
	Seasonal best speed (m/s)	36	12.14	13.50	12.98	0.35
	Personal best speed (m/s)	36	12.31	13.50	13.06	0.32
1500m	Age (years)	39	19	35	24.72	3.24
	Length (meters)	39	1.56	1.80	1.68	0.06
	Weight (kilograms)	39	52	75	61.62	5.31
	Body mass index (kg/m^2)	39	19.57	25.51	21.86	1.18
	Seasonal best speed (m/s)	39	11.91	13.09	12.51	0.35
	Personal best speed (m/s)	39	12.03	13.11	12.60	0.37
3000m	Age (years)	32	19	35	24.81	3.62
	Length (meters)	32	1.56	1.80	1.68	0.06
	Weight (kilograms)	32	52	74	61	5.11
	Body mass index (kg/m^2)	32	19.57	23.51	21.64	1.09
	Seasonal best speed (m/s)	32	10.92	12.45	11.84	0.35
	Personal best speed (m/s)	32	11.39	12.54	11.95	0.33
5000m	Age (years)	16	21	33	25.94	2.91
	Length (meters)	16	1.62	1.75	1.68	0.04
	Weight (kilograms)	16	56	72	60.88	4.30
	Body mass index (kg/m^2)	16	20.55	23.51	21.64	0.81
	Seasonal best speed (m/s)	16	10.53	11.93	11.45	0.39
	Personal best speed (m/s)	16	10.71	11.96	11.62	0.31

Table 5. Estimation results for the men events.

Dependent variable: $\boldsymbol{SPEED_{ij}}$ = speed (in meters per second) of athlete *j* in lap *i*.

Explanatory variables (regressors):

$\boldsymbol{AGE_j}$ = Age of the athlete (years);

$\boldsymbol{BMI_j}$ = Body mass index (length in meters divided by squared weight in kilograms);

$\boldsymbol{SBS_j}$ = Speed of the seasonal best race prior to the 2002 Olympicgames (m/s);

$\boldsymbol{POT_j}$ = Potential performance (ratio of season best speed and personal best speed);

$\boldsymbol{FLAT_j}$ = The ability to skate a “flat” scheme (coefficient of variation);

$\boldsymbol{HOME_j}$ = Dummy-variable representing home athletes (USA);

$\boldsymbol{LANE_j}$ = Dummy-variable representing starting lane (in=1, out=0);

$\boldsymbol{NIKE_j}$ = Dummy-variable representing Nike’s suit (Nike=1, other=0);

$\boldsymbol{HUNT_j}$ = Dummy-variable representing Hunter’s suit (Hunter=1, other=0);

$\boldsymbol{MIZU_j}$ = Dummy-variable representing Mizuno’s suit (Mizuno=1, other=0);

$\boldsymbol{GENE_j}$ = Dummy-variable representing a generic suit (generic=1, other=0);

$\boldsymbol{DESC_j}$ = Dummy-variable representing Descente’s suit (Descente=1, other=0);

R^2 = determination coefficient;

SSR = sum of squared residuals.

The standard errors are in parentheses. We included intercepts for laps (fixed effects).

Regressor	500m	1000m	1500m	5000m	10000m
AGE	-0.004	-0.005	0.003	-0.008	0.005
	(0.004)	(0.007)	(0.005)	(0.005)	(0.006)
BMI	0.023	0.035 [a]	-0.015	-0.019	-0.020
	(0.012)	(0.016)	(0.012)	(0.014)	(0.013)
SBS	0.795 [a]	0.730 [a]	0.872 [a]	0.785 [a]	-0.124
	(0.082)	(0.085)	(0.099)	(0.184)	(0.187)
POT	-13.439 [a]	-10.206 [a]	-6.592 [a]	-8.407 [a]	-1.615
	(5.400)	(2.884)	(2.107)	(1.714)	(1.471)
FLAT	- [b]	- [b]	-0.074	-8.418 [a]	-5.953 [a]
			(1.376)	(1.055)	(1.366)
HOME	0.018	-0.099	0.055	0.530 [a]	-0.089
	(0.056)	(0.096)	(0.081)	(0.103)	(0.082)
LANE	0.047	-0.029	0.055	- [b]	- [b]
	(0.026)	(0.044)	(0.034)		
NIKE-GENE	0.085 [a]	0.193 [a]	0.162 [a]	0.059	0.241 [a]
	(0.043)	(0.058)	(0.047)	(0.061)	(0.053)
HUNT-GENE	-0.099	-0.105	-0.035	-0.016	-0.012
	(0.098)	(0.066)	(0.051)	(0.040)	(0.045)
DESC-GENE	-0.018	-0.031	-0.075	-0.072	-0.216 [a]
	(0.042)	(0.057)	(0.047)	(0.040)	(0.052)
MIZU-GENE	0.035	-0.015	-0.082 [a]	-0.005	-0.073 [a]
	(0.032)	(0.043)	(0.034)	(0.027)	(0.030)
R^2	0.998	0.996	0.998	0.991	0.994
SSR	2.504	5.500	9.075	30.037	32.069
# observations	132	120	180	390	400
# cross-sections	2	3	4	13	25

[a] Estimates significant at 5%.

[b] Not included

Table 6. Estimation results for the women events.

Dependent variable: $\boldsymbol{SPEED_{ij}}$ = speed (in meters per second) of athlete *j* in lap *i*.

Explanatory variables (regressors):

$\boldsymbol{AGE_j}$ = Age of the athlete (years);

$\boldsymbol{BMI_j}$ = Body mass index (length in meters divided by squared weight in kilograms);

$\boldsymbol{SBS_j}$ = Speed of the seasonal best race prior to the 2002 Olympic games (m/s);

$\boldsymbol{POT_j}$ = Potential performance (ratio of season best speed and personal best speed);

$\boldsymbol{FLAT_j}$ = The ability to skate a “flat” scheme (coefficient of variation);

$\boldsymbol{HOME_j}$ = Dummy-variable representing home athletes (USA);

$\boldsymbol{LANE_j}$ = Dummy-variable representing starting lane (in=1, out=0);

$\boldsymbol{NIKE_j}$ = Dummy-variable representing Nike’s suit (Nike=1, other=0);

$\boldsymbol{HUNT_j}$ = Dummy-variable representing Hunter’s suit (Hunter=1, other=0);

$\boldsymbol{DESC_j}$ = Dummy-variable representing Descente’s suit (Descente=1, other=0);

$\boldsymbol{MIZU_j}$ = Dummy-variable representing Mizuno’s suit (Mizuno=1, other=0);

$\boldsymbol{GENE_j}$ = Dummy-variable representing a generic suit (generic=1, other=0);

R^2 = determination coefficient;

SSR = sum of squared residuals.

The standard errors are in parentheses. We included intercepts for laps (fixed effects).

Regressor	500m	1000m	1500m	3000m	5000m
AGE	-0.001	-0.003	0.003	0.011 [a]	-0.004
	(0.004	(0.006)	(0.007)	(0.005)	(0.012)
BMI	-0.010	0.005	0.056 [a]	0.015	0.049
	(0.012)	(0.020)	(0.018)	(0.017)	(0.039)
SBS	1.029 [a]	0.960 [a]	0.792 [a]	0.815 [a]	0.810 [a]
	(0.080)	(0.081)	(0.066)	(0.066)	(0.105)
POT	-1.762	-7.147 [a]	-0.748	-6.137 [a]	-8.925 [a]
	(3.487)	(2.135)	(2.969)	(1.607)	(2.333)
FLAT	- [b]	- [b]	-2.512 [a]	-4.486 [a]	-7.191 [a]
			(1.116)	(1.382)	(1.616)
HOME	-0.008	-0.074	-0.079	-0.065	-0.109
	(0.061)	(0.083)	(0.091)	(0.072)	(0.103)
LANE	-0.004	0.052	-0.025	- [b]	- [b]
	(0.025)	(0.042)	(0.037)		
NIKE-GENE [c]	0.003	0.070	0.160 [a]	0.172 [a]	0.131 [a]
	(0.034)	(0.049)	(0.056)	(0.041)	(0.044)
HUNT-GENE [c]	- [d]	- [d]	- [d]	- [d]	- [d]
DESC-GENE [c]	-0.118 [a]	-0.035	-0.087	-0.015	-0.168 [a]
	(0.045)	(0.056)	(0.052)	(0.048)	(0.045)
MIZU-GENE [c]	-0.036	-0.007	-0.039	-0.078	- [d]
	(0.023)	(0.033)	(0.035)	(0.026)	
R^2	0.998	0.998	0.996	0.993	0.996
SSR	1.762	3.692	7.125	15.547	14.322
# observations	112	102	152	256	182
# cross-sections	2	3	4	8	13

[a] Estimates significant at 5%.

[b] Not included.

[c] For the Women's 5000 meter event the Mizuno suit was used as a benchmark instead of the generic suit.

[d] No observations.

Table 7. The effects of the suits for the men events.

Suit manufacturer	500m	1000m	1500m	5000m	10000m
Nike	0.085 [a]	0.193 [a]	0.162 [a]	0.059	0.241 [a]
Hunter	-0.099	-0.105	-0.035	-0.016	-0.012
Descente	-0.018	-0.031	-0.075	-0.072	-0.216 [a]
Mizuno	0.035	-0.015	-0.082 [a]	-0.005	-0.073 [a]
Generic	-0.003	-0.042	0.030	0.034 [a]	0.060

[a] Estimates significant at 5%.

Table 8. The effects of the suits for the women events.

Suit manufacturer	500m	1000m	1500m	3000m	5000m
Nike	0.003	0.070	0.160 [a]	0.172 [a]	0.131 [a]
Hunter	- [b]	- [b]	- [b]	- [b]	- [b]
Descente	-0.118 [a]	-0.035	-0.087	-0.015	-0.168 [a]
Mizuno	-0.036	-0.007	-0.039	-0.078 [a]	0.037
Generic	0.151 [a]	-0.028	-0.034	-0.079	- [b]

[a] Estimates significant at 5%.

[b] No observations.

Table 9. Estimation results for the binary logit models.

Dependent variable: ***NIKE*** = Dummy-variable representing Nike's suit (Nike=1, other=0) of athlete/team.

Explanatory variable: ***RANK***= Individual ranking for speedskating (season 2000/2001); ***RANK*** = ISU Cyberscoreboard team ranking for short track (season 2000/2001).

FAD = McFadden's R^2;

SSR = sum of squared residuals;

LR = Log-likehood ratio;

Prob = *LR* probability value.

The standard errors are in parentheses.

	Long track speedskating		Short track	
Regressor	Men	Women	Men	Women
Constant	-0.813 [a]	-0.666 [a]	-0.794	-1.885
	(0.268)	(0.250)	(1.261)	(1.777)
RANK	-0.013 [a]	-0.017 [a]	-0.086	0.062
	(0.007)	(0.004)	(0.148)	(0.250)
FAD	0.054	0.069	0.023	0.006
SSR	26.180	23.918	2.414	1.633
LR	9.315	10.639	0.350	0.061
Prob	0.002	0.001	0.554	0.804
# obs *NIKE*=0	131	116	13	9
# obs *NIKE*=1	35	32	3	2

[a] Estimates significant at 5%.

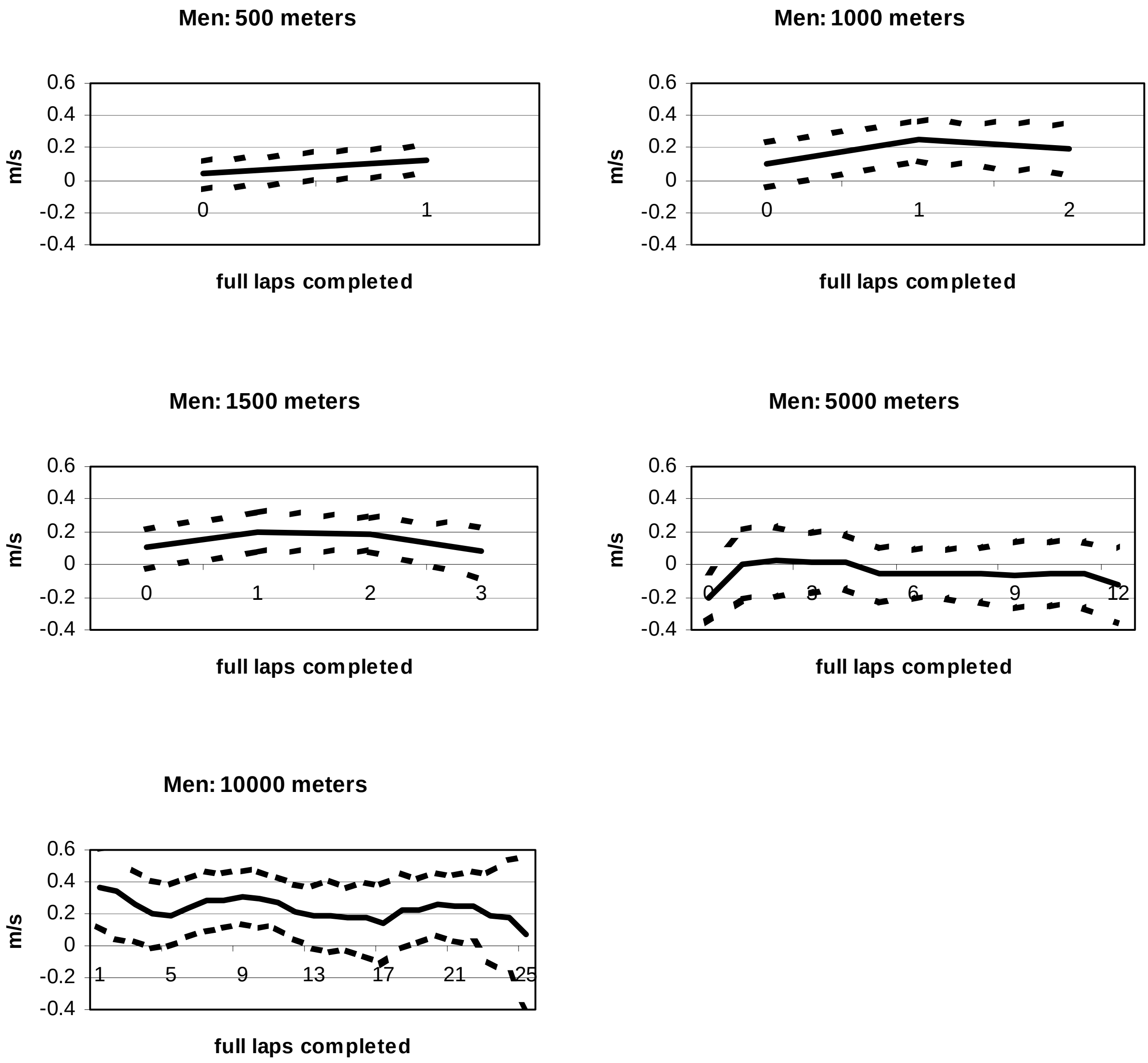

Figure 1. The effect of the Nike suit during men's race (parameter estimates and the 95% confidence intervals).

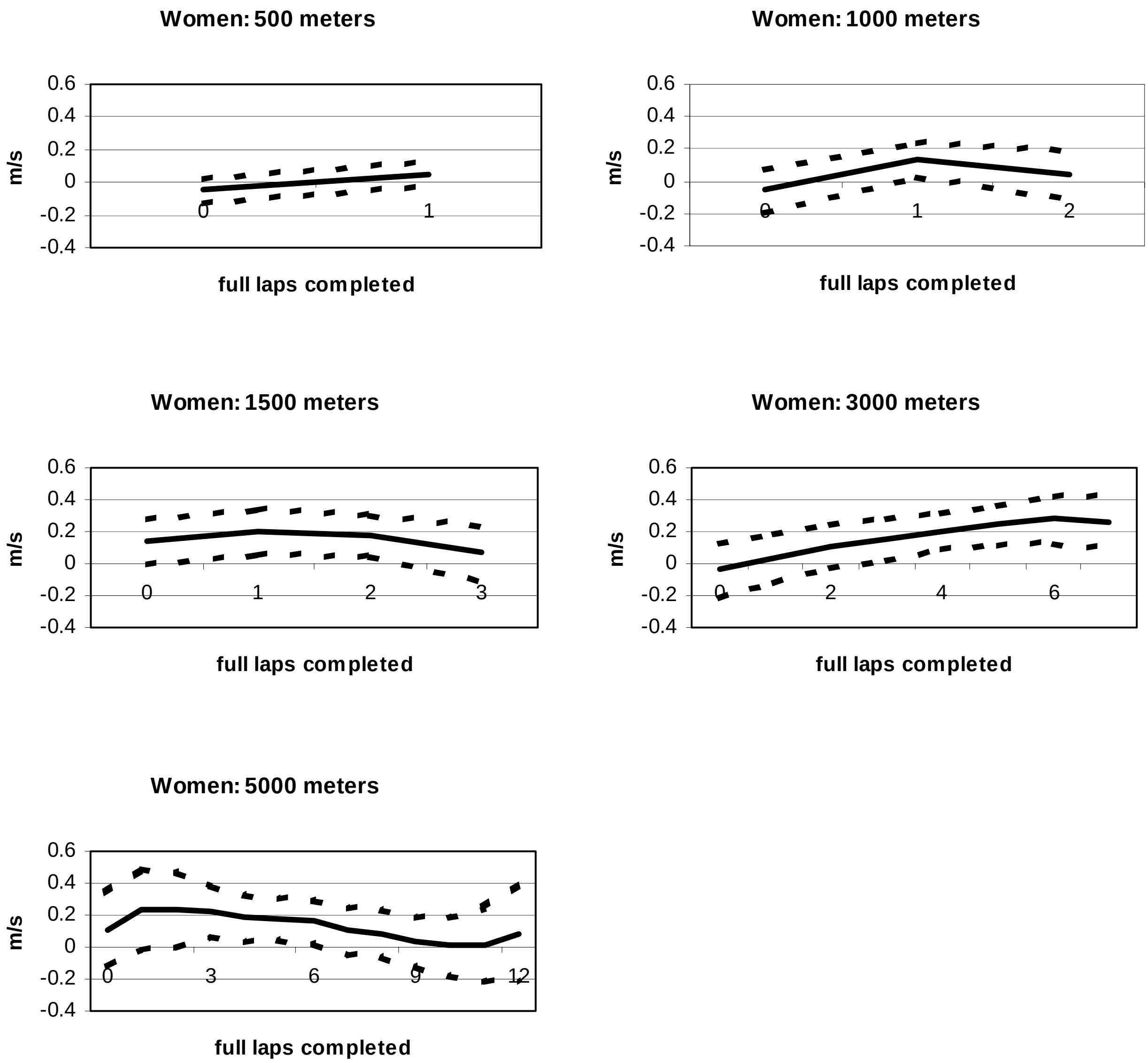

Figure 2. The effect of the Nike suit during the women's races (parameter estimates and the 95% confidence intervals).