Collaborative Sciences Center for
ROAD SAFETY

www.roadsafety.unc.edu

Investigating the Vulnerability of Motorcyclists to Crashes and Injury

Collaboration: University of Tennessee, Knoxville;
University of North Carolina, Chapel Hill

R20 Project Team

- **UT Knoxville**
  - Prof. Asad J. Khattak
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- **UNC Chapel Hill**
  - Arthur Goodwin

THE UNIVERSITY OF TENNESSEE KNOXVILLE

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

Overview

Research Objectives:

The project addresses four critical safety issues related to motorcyclists:

1. Motorcycle crash risk factors, especially how visual conspicuity (bright-colored or reflective clothing) influences their likelihood of being involved in a crash?
2. How the frequency and causes of crashes among young and inexperienced riders differ from those of older, experienced riders?
3. How training & education programs relate to crash outcomes?
4. New automation technologies that can reduce identified risks in motorcycle crashes based on analysis of motorcycle crash risk factors.

Overview

Research Questions:

1. While controlling for rider-specific, psycho-physiological, and other observed/unobserved factors, how are different risk factors associated with motorcycle crash occurrence and injury severity?
2. How does motorcyclist conspicuity relate to crash risk?
3. How can ignoring important methodological issues such as omitted variable biases and unobserved heterogeneity influence the magnitude of relative risks (or odds ratios) and final inferences?
4. How does age and inexperience contribute to motorcycle crash outcomes and occurrences?
5. How do training & education programs impact crash outcomes?
6. How can automation eliminate errors associated with motorcycle crashes?
7. While using a different scoring system to measure injury severity and controlling for rider and crash specific factors as well as other observed/unobserved factors, how do different "policy-sensitive" factors correlate with injury severity?

R20 Project: Studies Conducted

Study I:

A Heterogeneity-Based Case-Control Analysis of Motorcyclist's Injury Crashes: Evidence from Motorcycle Crash Causation Study

Study II:

Modeling Injury Severity Score as a More Precise Measure of Motorcyclist Injuries: A Correlated Random Parameter Corner Solution Framework

Study I (Project R20)

A Heterogeneity-Based Case-Control Analysis of Motorcyclist's Injury Crashes: Evidence from Motorcycle Crash Causation Study

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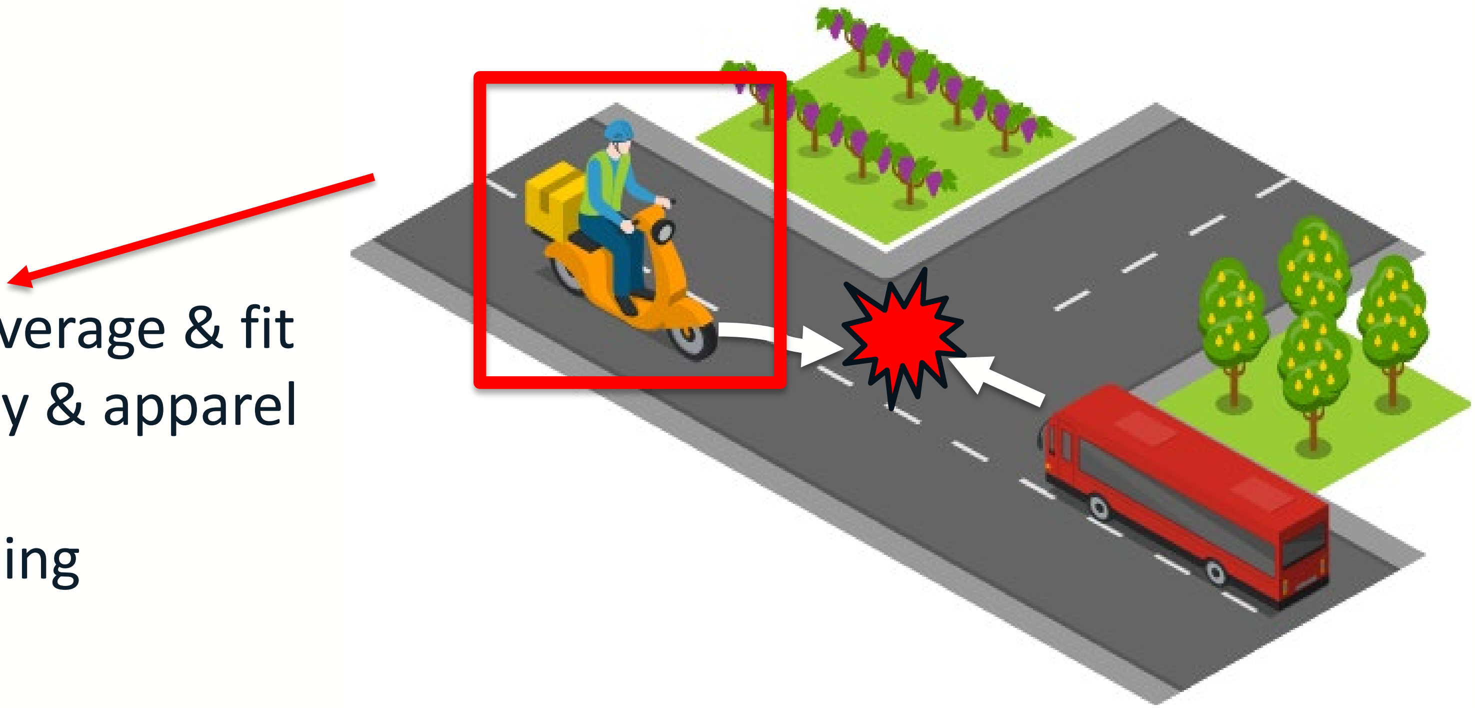
Introduction

- Anatomy of motorcycle crash >> Motorcycle crash is a violent event
- **Vehicle Differences:** Motorcycle lacks the crashworthiness & occupant protection features of an automobile

Key Question

- How behavioral, psycho-physiological, & exposure related factors relate to injury crash likelihood?



- Helmet coverage & fit
- Conspicuity & apparel type
- Rider training
- Fatigue

Conceptual Framework

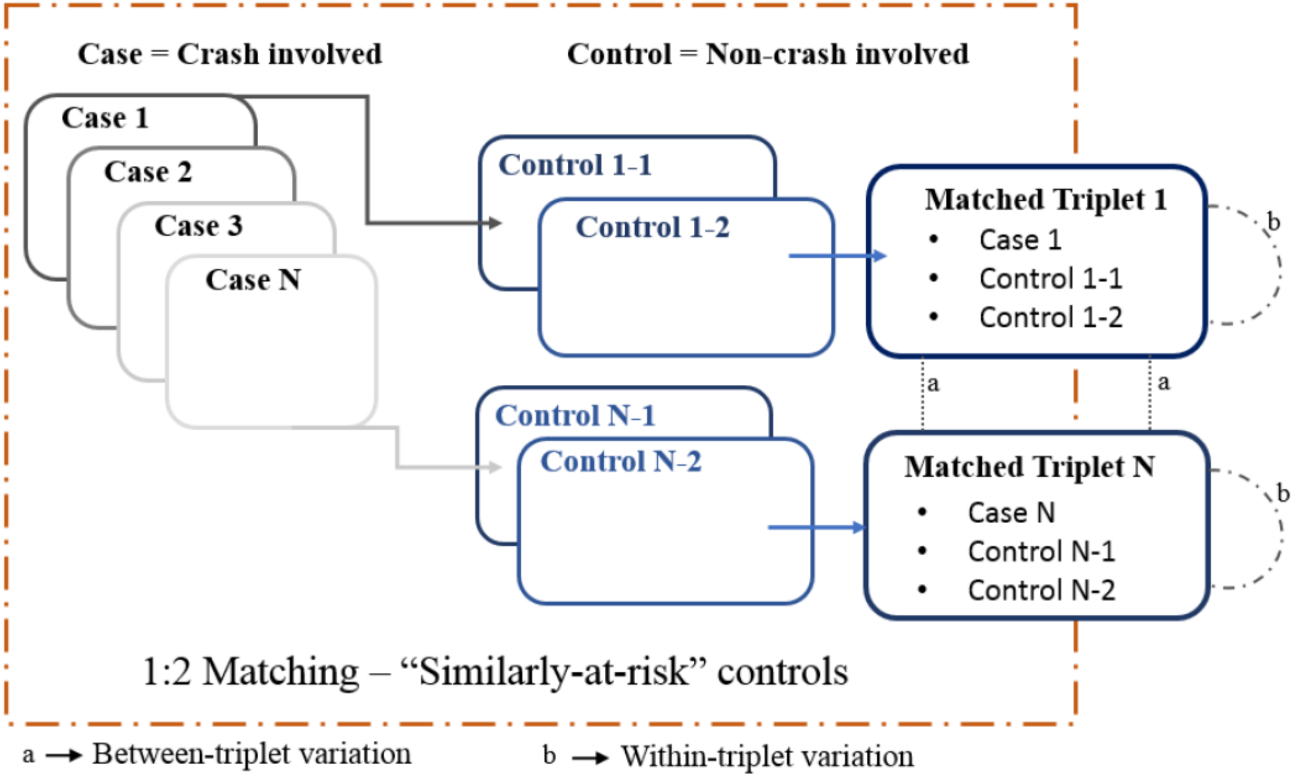


FIGURE 1: A Retrospective Matched Case-Control Approach

- 351 cases *(riders involved in injury crashes)*
- Similarly-at-risk 702 matched controls *(riders not involved in injury crashes)*

- 33% are injury crashes and the rest baseline (no-crash) by design.

Methodological Framework

- Dependent Variable – Injury Crash Propensity (0/1)
- Hierarchical grouped random parameter logit model with heterogeneous means

Random Heterogeneity

Heterogeneity due to unobserved factors (unobserved heterogeneity)

Systematic component of random heterogeneity - *observed* heterogeneity

Remaining component of random heterogeneity – *unobserved* heterogeneity

Between observation/ between-triplet heterogeneity

Selected Descriptive Statistics (See paper for details)

Variables	Crash Group (N = 351)		Non-Crash Group (N = 702)		Mean Comparison Test --- Ho: μ2 - μ1 = 0
	μ1	Min/Max	μ2	Min /Max	
Type of helmet coverage					
Helmet coverage type 1 (Partial coverage)	**0.12**	0/1	**0.32**	0/1	Fail
Helmet fit (1 if acceptable fit, 0 otherwise)	**0.50**	0/1	**0.94**	0/1	Fail
Physical/psychological factors					
No psychological impairment	0.44	0/1	0.81	0/1	Fail
Hours of sleep prior to event	**7.67**	2/12	**8.12**	1/16	Fail
Exposure-related factors					
Motorcycle riding experience in years	**11.52**	0/46	**20.48**	0/69	Fail
Total miles driven prior to event	**10.35**	1/96	**19.05**	1/600	Fail
Number of traffic convictions in last 5 years					
One traffic conviction	0.16	0/1	0.23	0/1	Fail
Driver's apparel					
Retroreflective upper body clothing	**0.13**	0/1	**0.20**	0/1	Fail
Lower clothing motorcycle oriented	**0.05**	0/1	**0.25**	0/1	Fail
Actual speed before event	**32.84**	0/90	**46.35**	0/85	Fail

Almost everyone was using helmet…

Model Selection

Goodness of Fit Measures	Models for individual observations (ignoring matched-triplet structure)				Models for matched-triplets (accounting for matched-triplet structure)		
	Model 1*	Model 2**	Model 3***	**Model 4********	Model 5**	Model 6***	Model 7****
N (obs.)	1053	1053	1053	**1053**	1053	1053	1053
# of triplets	---	---	---	**---**	351	351	351
Degrees of Freedom	24	31	32	**39**	31	32	40
AIC	659.4	639.2	641.5	**633.2**	649.4	652.2	662.8

After accounting for systematic & random heterogeneity, **no** significant "within" triplet dependence and variation is observed.

Notes:
* Fixed parameter model
** Random parameters model
*** Random intercept and random parameters model
**** Random parameters/random intercepts with heterogeneity-in-means

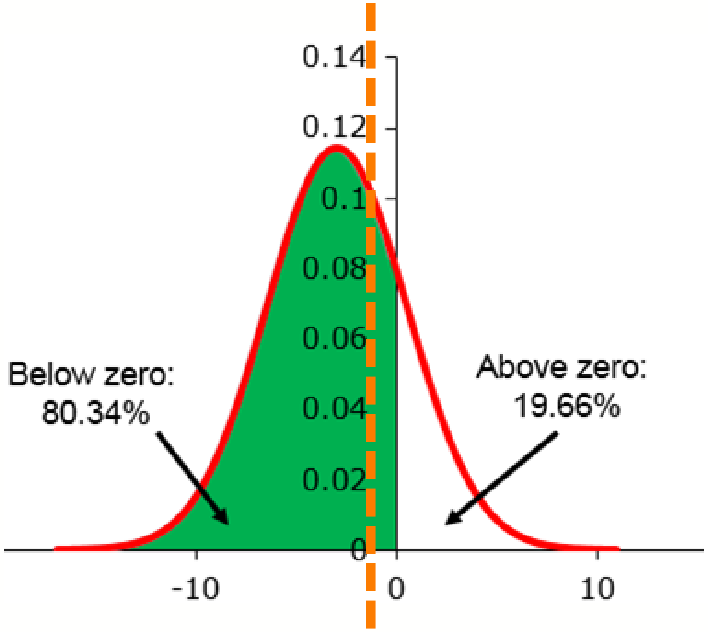
Selected Results (Relative Risk Estimates)

Variables	Model 1 Fixed Parameter Logit		Model 2 Random Parameter Logit		Model 4 Random Parameter Logit - Heterogeneity in Means	
	Direction of effect	% change in crash risk	Direction of effect	% change in crash risk	Direction of effect	% change in crash risk
Number of traffic convictions in last 5 years						
Three traffic convictions	↑	62.26	[↓]	-98.93	[↓][a]	-101.00
Clothing color						
Lower clothing motorcycle oriented	↓	-77.62	[↓]	-98.91	[↓]	-99.85
Dark Upper body clothing color	↑	209.88	↑	254.31	↑	297.49
Driver-related factors						
5 hours or less sleep	↑	150.93	↑	191.54	↑	197.43
Female driver	↑	50.68	[↓]	-6.39	[↑][a]	47.70
Type of helmet coverage						
Partial coverage – USDOT compliant least intrusive helmet	↓	-53.23	↓	-51.81	↓	-49.34
Year of training						
Training between 2001-2010	↓	-65.01	↓	-70.09	↓	-68.34
Training between 2011- 2015	↓	-73.55	↓	-77.26	↓	-76.07

Notes: (*) Brackets indicate mixed effects for the random-held parameters; (a) indicates random parameters with heterogeneity-in-means.

Illustration: Observed & Unobserved Heterogeneity Effects

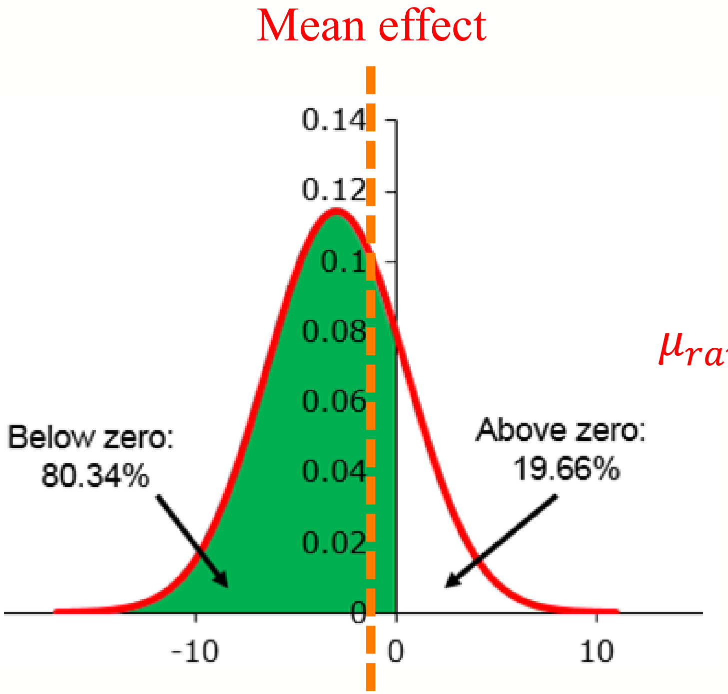
Mean effect



"Unobserved Heterogeneity"

Effects of speed on crash propensity (probability density)

Illustration: Observed & Unobserved Heterogeneity Effects



$\mu_{random\ parameter\ -Speed} = f(alcohol\ or\ multiple\ drugs)$

"Observed Heterogeneity"

Effects of speed on crash propensity (probability density)

Conclusions

- Compared to traditional conditional estimation of relative risks, heterogeneity based case-control analysis provides deeper insights.
- Reductions in motorcycle injury crashes are possible by:

Encouraging "proper" helmet use

Increasing rider conspicuity

Using motorcycle-oriented clothing

Conclusions

- Further reductions in injury crashes can be achieved by:
  - On-going participation in training programs (especially refresher courses for experienced riders)
  - Preventing sleep-deprived/fatigued riding
  - Reducing riding under the influence of alcohol (especially at high speeds)

Future Work/Work In Progress

- Need to quantify # of lives that can be saved or injuries prevented with "high-priority" interventions

Table 1 - Lives Saved by Motorcycle Helmets In 2003

Motorcyclists	Effectiveness	Fatalities			Lives Saved	Potential Lives Saved
		Total	Helmeted	Unhelmeted		
Operators	0.37	3,382	1,805	1,577	1,060	1,644
Passengers	0.41	279	141	138	98	154
Total	0.37	3,661	1,946	1,715	1,158	1,798

- Estimate the population that will benefit from these interventions
- Microscopic injury analysis >> Chronic disease & public health perspective

Study II (Project R20)

Modeling Injury Severity Score as a More Precise Measure of Motorcyclist Injuries: A Correlated Random Parameter Corner Solution Framework

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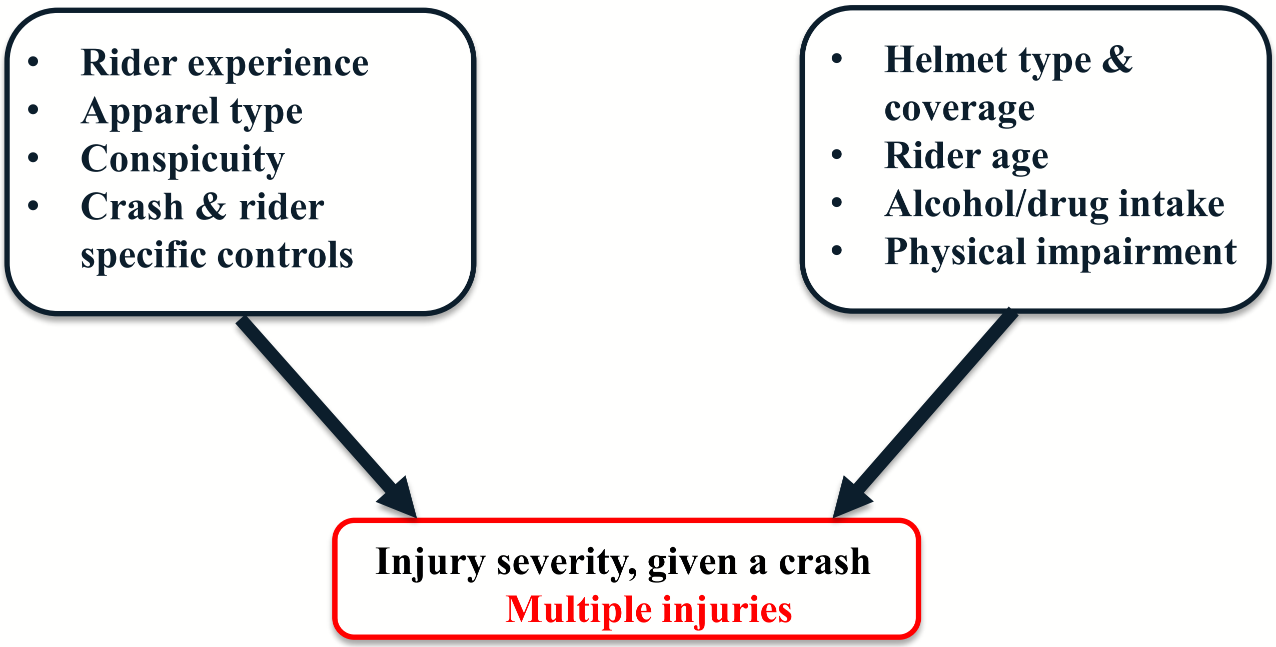
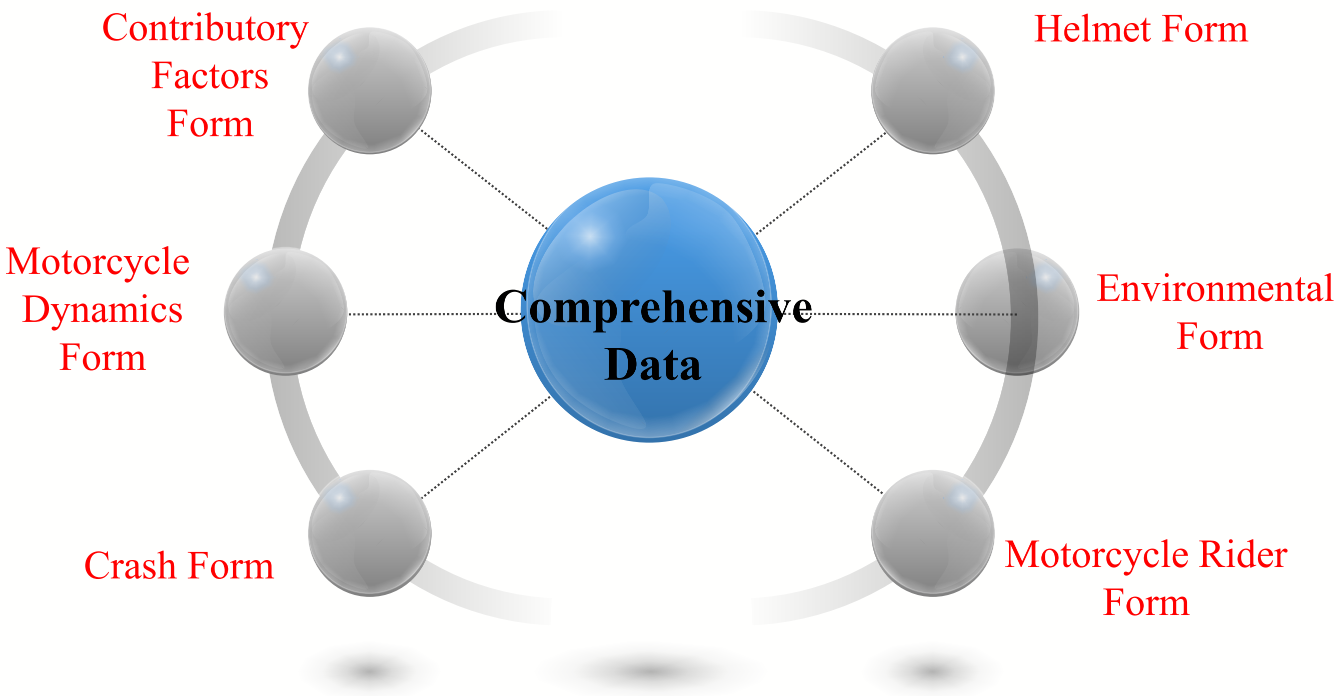
Introduction - Notice Anything?

Motorcyclist deaths occurred **28 times** more frequently than fatalities in other vehicles (NHTSA, 2016)

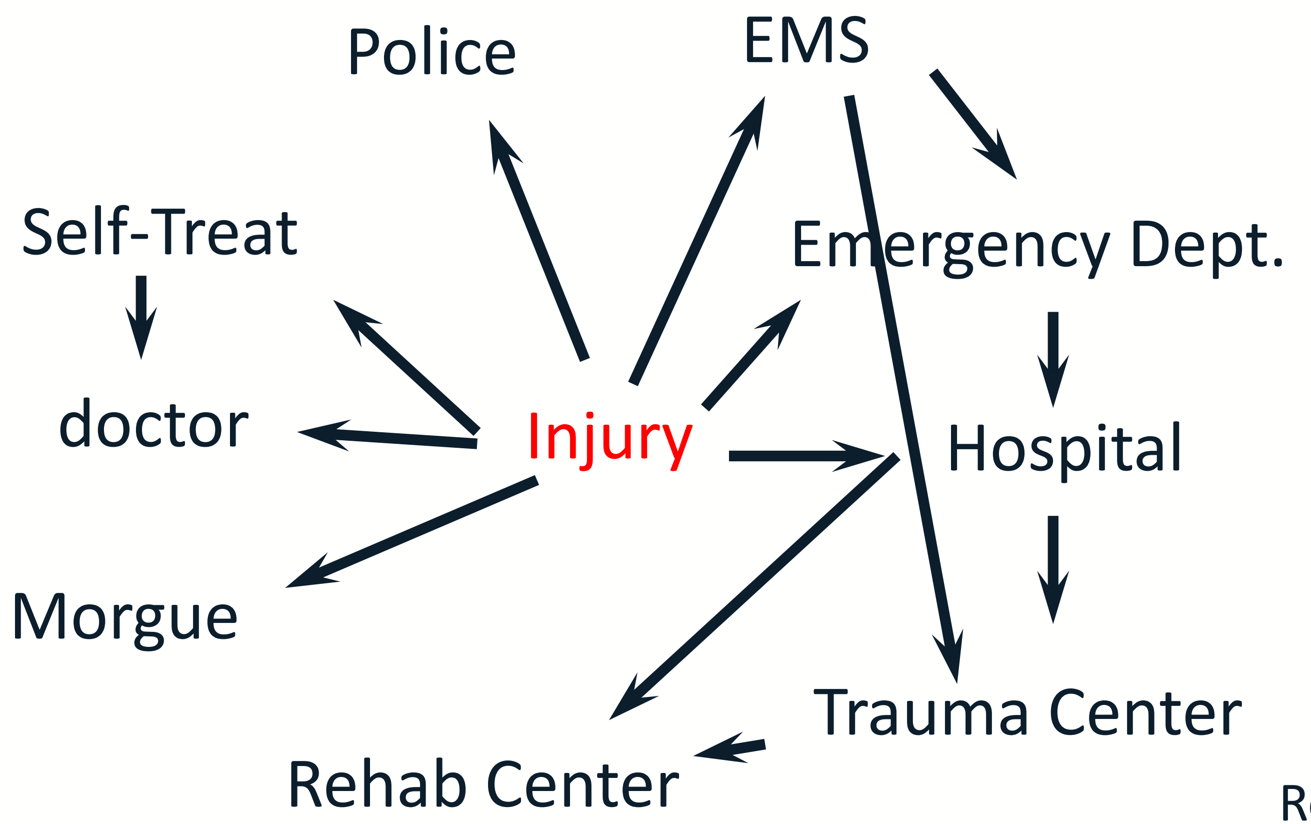
Key Objectives



Data Linkage



Measuring Injury Severity – A Case for Better Measures



Robertson, 1992

Perspectives on Injury Severity

Anatomical Injury

Physiological Measurements

Age
Blunt/Penetrating

Chance of survival of individual patients

*Majority of the safety literature is based on **police-reported KABCO scale.***

Present Study: Anatomical Injury Severity Measures

AIS

1 MINOR
2 MODERATE
3 SERIOUS
4 SEVERE
5 CRITICAL
6 MAXIMUM INJURY, VIRTUALLY UNSURVIVABLE

Addressing Multiple Injuries for Predicting survival

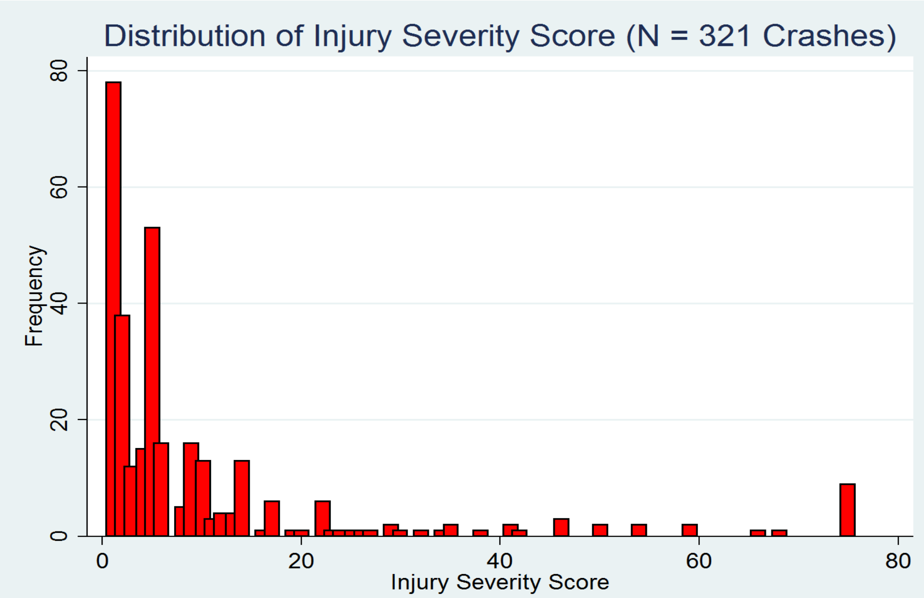
Injury Severity Score

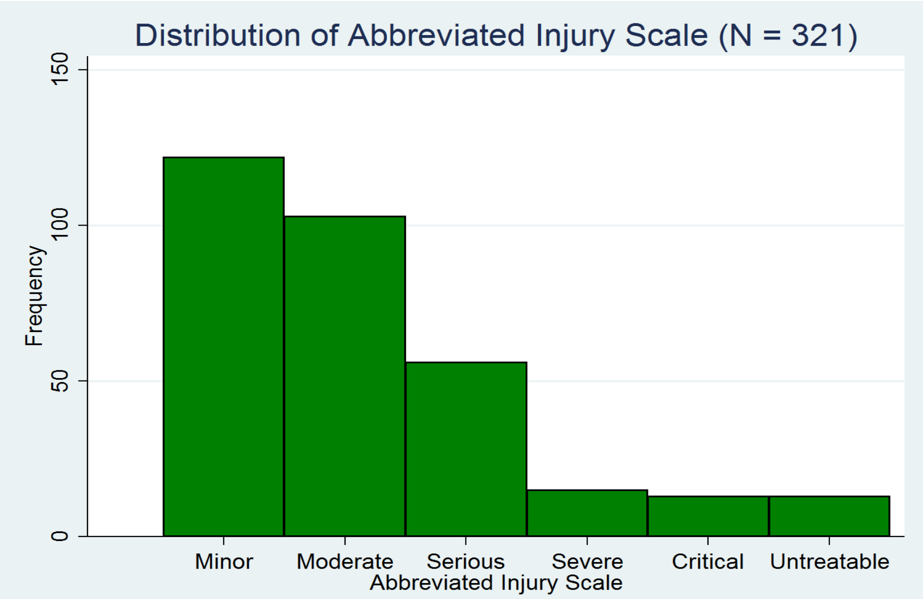
$$ISS = A^2 + B^2 + C^2$$

Six ISS Body Regions:

- Head or neck
- Face
- Abdominal
- Chest
- Extremities
- External

Distributions of ISS & AIS





Results: AIS Vs. ISS

ISS Categories / AIS Categories	ISS (1-3): Minor	ISS (4-8): Moderate	ISS (9-15): Serious	ISS (16-24): Severe	ISS (25-35): Critical	ISS (36-75): Maximum (Untreatable)	Total
Minor Injury	121	1	0	0	0	0	122
	99.18	0.82	0	0	0	0	100
	94.53	1.12	0	0	0	0	38.01
Moderate Injury	4	85	14	0	0	0	103
	3.88	82.52	13.59	0	0	0	100
	3.13	95.51	26.42	0	0	0	32.09
Serious Injury	1	2	39	12	1	0	55
	1.82	3.64	70.91	21.82	1.82	0	100
	0.78	2.25	73.58	70.59	10	0	17.13
Severe Injury	2	0	0	5	6	2	15
	13.33	0	0	33.33	40	13.33	100
	1.56	0	0	29.41	60	8.33	4.67
Critical	0	1	0	0	3	9	13
	0	7.69	0	0	23.08	69.23	100
	0	1.12	0	0	30	37.5	4.05
Maximum (Untreatable)	0	0	0	0	0	13	13
	0	0	0	0	0	100	100
	0	0	0	0	0	54.17	4.05
Total	128	89	53	17	10	24	321
	39.88	27.73	16.51	5.3	3.12	7.48	100
	100	100	100	100	100	100	100
Measures of Association	Pearson χ^2 (25) = 855.1792; p-value = 0.000						
	Kendall's τ_b rank coefficient = 0.9111; Asymptotic Standard Error = 0.019						

Results: AIS Vs. ISS

*"100 percent of injuries classified as maximum (untreatable) injuries By **AIS** are classified likewise by **ISS**"*

ISS Categories / AIS Categories	ISS (1-3): Minor	ISS (4-8): Moderate	ISS (9-15): Serious	ISS (16-24): Severe	ISS (25-35): Critical	ISS (36-75): Maximum (Untreatable)	Total
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	0	1.12	0	0	30	37.5	4.05
Maximum (Untreatable)	0	0	0	0	0	**13**	13
	0	0	0	0	0	**100**	100
	0	0	0	0	0	54.17	4.05
Total	128	89	53	17	10	24	321
	39.88	27.73	16.51	5.3	3.12	7.48	100
	100	100	100	100	100	100	100
Measures of Association	Pearson χ^2 (25) = 855.1792; p-value = 0.000						
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Results: AIS Vs. ISS

AIS can underestimate the 'true' injury severity sustained by a rider.

ISS Categories / AIS Categories	ISS (1-3): Minor	ISS (4-8): Moderate	ISS (9-15): Serious	ISS (16-24): Severe	ISS (25-35): Critical	ISS (36-75): Maximum (Untreatable)	Total
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Measures of Association	Pearson χ^2 (25) = 855.1792; p-value = 0.000						
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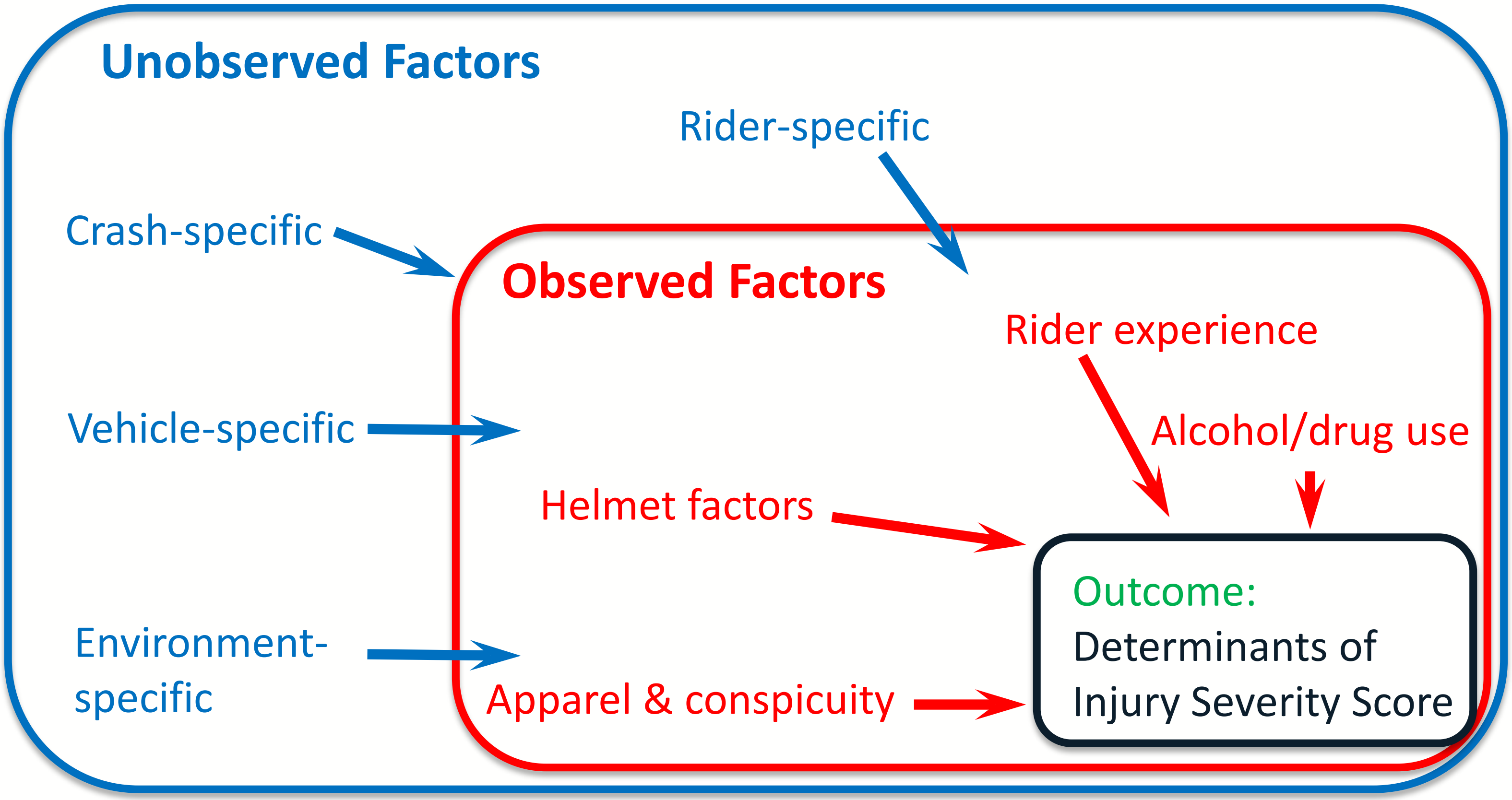
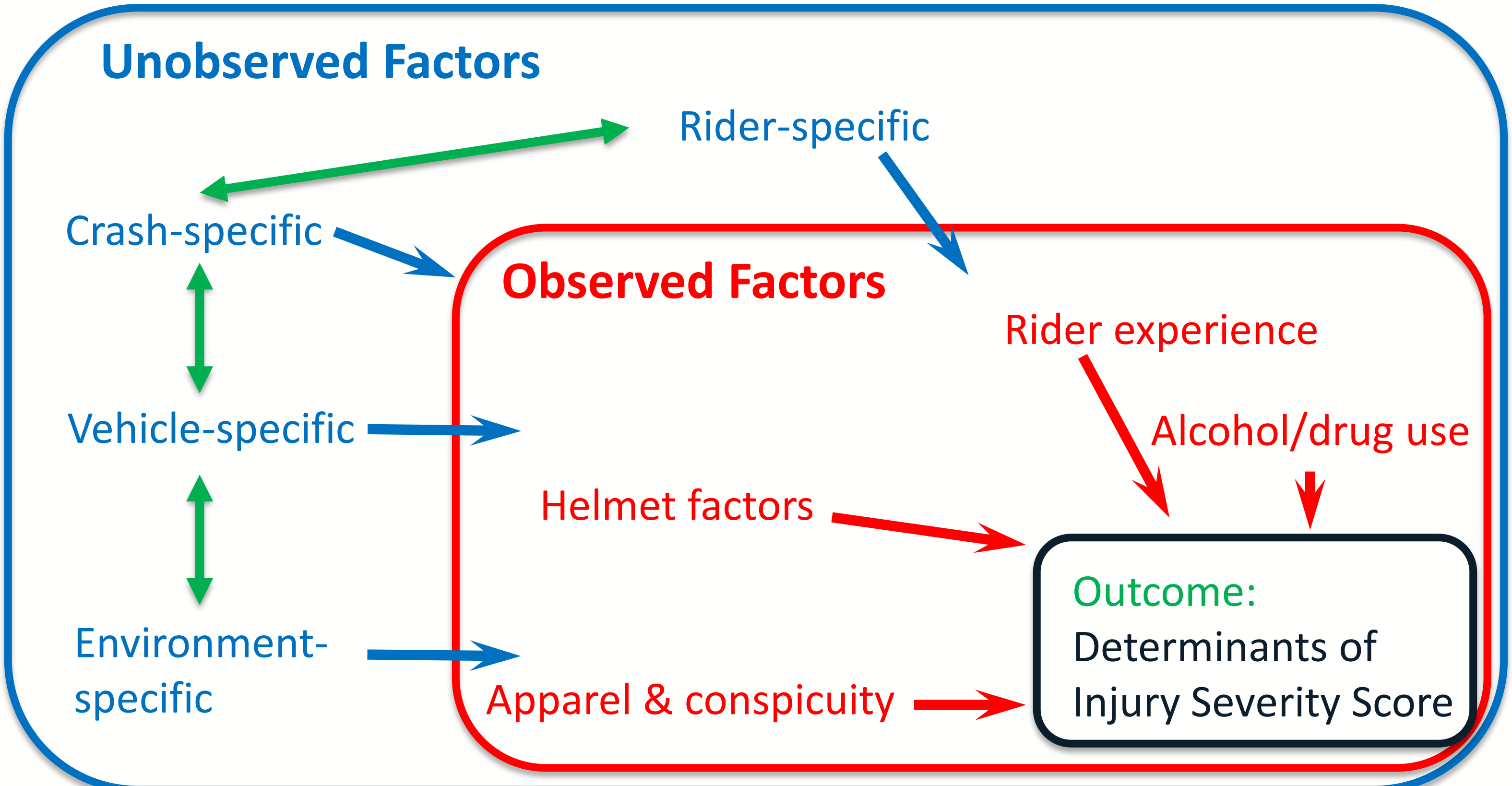
Empirical Analysis – Injury Severity Score

- Corner-solution Vs. censoring (Left-spike at ISS = 1)
- Application of Tobit model in a ‘corner-solution’ setup
- Methodological Issues: Correlated & uncorrelated unobserved heterogeneity
- AIS was compared with ISS and ISS was found to be better based on theory and empirical evidence (goodness-of-fit) (Results not shown)

Empirical Analysis – Uncorrelated Random Parameters



Empirical Analysis – Correlated Random Parameters



Selected Descriptive Statistics (See paper for details)

Variables (N = 321)	Mean	SD	Min	Max	VIF
Dependent Variable: Rider Injury Severity Score	10.320	15.976	1	75	
	1st Quartile = 19.50; Midpoint = 38; 3rd Quartile = 56.500; Spike at 1 = 78 observations				
Rider Experience Related Factors					
Gap exists between riding (1/0)	0.20	0.40	0	1	1.45
Experienced rider course (1/0)	0.05	0.21	0	1	1.14
Rider Apparel & Conspicuity Related Factors					
Upper body clothing retroreflective (1/0)	**0.14**	0.35	0	1	1.57
Upper clothing MC oriented (1/0)	**0.34**	0.47	0	1	1.81
Shoes MC oriented (1/0)	**0.17**	0.37	0	1	1.35
Dark blue color waist down clothing (1/0)	0.37	0.48	0	1	1.43
Helmet color (multicolor)	0.07	0.26	0	1	1.47
Helmet color (White)	0.06	0.24	0	1	1.33
Helmet color (silver, grey)	**0.06**	0.23	0	1	1.25
Helmet color (Black)	**0.43**	0.50	0	1	2.01
Helmet Related Factors					
Half face motor vehicle, motorcycle helmet (1/0)	0.11	0.31	0	1	1.25
Acceptable helmet fit (1/0)	**0.55**	0.50	0	1	2.92

Selected Estimation Results (Marginal Effects)

	Fixed Parameter Tobit	
Variables	ME-1	ME-2
Rider Apparel & Conspicuity Related Factors		
Upper body clothing retroreflective (1/0)	-2.58	-1.81
Shoes MC oriented (1/0)	-3.42	-2.40
Upper clothing MC oriented (1/0)	4.03	2.83
Blue color waist down clothing (1/0)	1.33	0.93
Helmet color (silver, grey)	-3.74	-2.62
Helmet color (Black)	4.87	3.42
Rider Experience Related Factors		
Gap exists between riding (1/0)	1.52	1.07
Experienced rider course (1/0)	-7.00	-4.92
Helmet Related Factors		
Half face motor vehicle, motorcycle helmet (1/0)	4.10	2.88
Acceptable helmet fit (1/0)	-5.93	-4.17

ME-1: Effect of a unit change in explanatory factor on the expected value of censored and uncensored ISS
ME-2 show the effect of a unit change in explanatory factor on the expected value of uncensored ISS outcomes

Selected Estimation Results (Marginal Effects)

Different types of marginal effects as are relevant in censored-regression framework may not be that relevant in heterogeneity-based Tobit modeling

	Fixed Parameter Tobit		Uncorrelated Random Parameter Tobit		Correlated Random Parameter Tobit	
Variables	**ME-1**	**ME-2**	**ME-1**	**ME-2**	**ME-1**	**ME-2**
Rider Apparel & Conspicuity Related Factors						
Upper body clothing retroreflective (1/0)	-2.58	-1.81	-2.04	-1.98	-1.89	-1.89
Shoes MC oriented (1/0)	-3.42	-2.40	-5.58	-5.42	-5.95	-5.94
Upper clothing MC oriented (1/0)	4.03	2.83	4.40	4.27	3.21	3.21
Blue color waist down clothing (1/0)	1.33	0.93	5.30	5.14	5.45	5.44
Helmet color (silver, grey)	-3.74	-2.62	-7.74	-7.51	-7.56	-7.55
Helmet color (Black)	4.87	3.42	5.44	5.28	4.25	4.25
Rider Experience Related Factors						
Gap exists between riding (1/0)	1.52	1.07	4.12	4.00	3.39	3.39
Experienced rider course (1/0)	-7.00	-4.92	-7.69	-7.46	-8.21	-8.20
Helmet Related Factors						
Half face motor vehicle, motorcycle helmet (1/0)	4.10	2.88	4.87	4.72	5.31	5.31
Acceptable helmet fit (1/0)	-5.93	-4.17	-9.56	-9.27	-8.82	-8.81

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Blue color waist down clothing (1/0)	1.33	0.93	5.30	5.14	5.45	5.44
Helmet color (silver, grey)	-3.74	-2.62	-7.74	-7.51	-7.56	-7.55
Helmet color (Black)	4.87	3.42	5.44	5.28	4.25	4.25
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Gap exists between riding (1/0)	1.52	1.07	4.12	4.00	3.39	3.39
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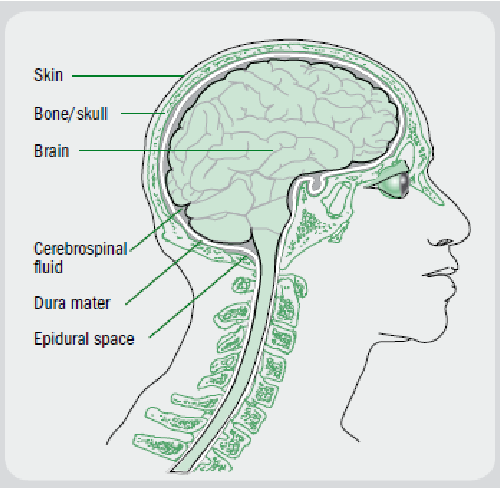
Half face motor vehicle, motorcycle helmet (1/0)	4.10	2.88	4.87	4.72	5.31	5.31
Acceptable helmet fit (1/0)	-5.93	-4.17	-9.56	-9.27	-8.82	-8.81
LL(β)	**-975.154**		**-935.175**		**-914.945**	
AIC	2004.3		1936.4		**1925.9**	

ME-1: Effect of a unit change in explanatory factor on the expected value of censored and uncensored ISS
ME-2 show the effect of a unit change in explanatory factor on the expected value of uncensored ISS outcomes

Mechanism of Head Injuries – Helmet Use & Helmet Color



Helmet color (light vs. dark)
Possible pathway: Helmet color influences injury outcomes through its mediating effect on rider conspicuity

Unobserved Heterogeneity Interactions

Correlated Random Parameter Tobit (URPT) Cholesky Matrix						
	Distance in feet between POI to POR (1 if > 9, 0 otherwise)	Time in seconds from precipitating event to impact (1 if > 2.3, 0 otherwise)	Half face motor vehicle, motorcycle helmet (1/0)	Acceptable helmet fit (1/0)	MC running off roadway, no OV involvement (1/0)	Positive BAC (1/0)
Distance in feet between POI to POR (1 if > 9, 0 otherwise)	15.03 [50.43] (1.00)					
Time in seconds from precipitating event to impact (1 if > 2.3, 0 otherwise)	1.34 [5.13] (0.113)	11.77 [43.47] (1.00)				
Half face motor vehicle, motorcycle helmet (1/0)	0.10 [0.21] (0.014)	-7.37 [-14.28] (-0.982)	0.99 [2.06] (1.00)			
Acceptable helmet fit (1/0)	2.61 [10.45] (0.470)	-0.87 [-3.88] (-0.102)	4.82 [24.15] (0.278)	0.23 [2.10] (1.00)		
MC running off roadway, no OV involvement (1/0)	-6.35 [-10.52] **(-0.226)**	18.48 [27.09] (0.629)	-7.40 [-12.93] (-0.692)	-10.21 [-17.78] (-0.454)	15.63 [26.66] (1.00)	
Positive BAC (1/0)	24.12 [36.30] **(0.758)**	-7.41 [-12.93] (-0.145)	8.69 [14.29] (0.278)	11.33 [18.18] (0.645)	-8.60 [-13.74] (-0.678)	9.79 [17.50] (1.00)

Conclusions

- Compared to ISS, AIS tends to underestimate the injury severity sustained by the rider
- ISS provides a more accurate approximation to mortality prediction
- Significant implications of ignoring correlated unobserved heterogeneity

Conclusions

- Motorcycle-specific shoes [ISS down by **5.94 units**]
- Retroreflective upper body clothing [ISS down by **1.88 units**]
- Riders with partial helmet coverage [ISS up by **5.31 units**]
- Riders with acceptable helmet fit [ISS down by **8.82 units**]
- Helmet color matters…

Future Work/Work In Progress

- In-depth comparison of other anatomical injury severity scales
  - ISS limits consideration of multiple injuries “within” a body region.
- In-depth analysis of injuries sustained by different body parts