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IMPROVING ON FLEXIBLE PAVEMENT IRI PREDICTIONS BY CORRECTING FOR POSSIBLE BIAS

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FEHRL

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Presentation Outline

- Background
  - M-E IRI Model
- IV Regression
  - Panel Data Models
- Dataset for Model Estimation
- IRI Estimation Model Results
- Conclusions

Background

- Concept of Serviceability
  - Related to pavement performance → PSR

$$PSR = 5.03 - 1.91 \cdot \log(1 + SV) - 0.01 \cdot (C + P)^{0.5} - 1.38 \cdot RD^2$$

- Serviceability is correlated to IRI

$$PSR = 5 \cdot \exp(-0.26 \cdot IRI)$$

Background

- IRI measurement has improved
  - Highway speeds (profiler)

- Models to directly predict IRI
  - M-E PDG

$$\mathrm{IRI} = \mathrm{IRI}_0 + \Delta\mathrm{IRI}_D + \Delta\mathrm{IRI}_F + \Delta\mathrm{IRI}_S$$

M-E IRI Model

- IRI Prediction Model

$$IRI = IRI_0 + 0.0150 \cdot (SF) + 0.400 \cdot (FC_{Total}) + 0.0080 \cdot (TC) + 40.0 \cdot (RD)$$

$$SF = Age \cdot [0.02003 \cdot (PI + 1) + 0.007947 \cdot (Precip + 1) + 0.000636 \cdot (FI + 1)]$$

M-E IRI Model

- Potential Problems:
  - Extrapolation of IRI to time of construction
  - Interpolation to match cracking/rutting observations
  - IRI estimated based on regression results

- Initial IRI should be captured thru intercept of model
  - Removes need for extrapolation

- Methods to account for correlation between regressors and unobserved factors

OLS Regression (M-E PDG)

- OLS

$$IRI_i = \beta_0 + \beta_1 \cdot (SF_i) + \beta_2 \cdot (FC_{Total\,i}) + \beta_3 \cdot (TC_i) + \beta_4 \cdot (RD_i) + \varepsilon_i$$

- OLS Assumptions
  - E(X'ε) = 0
  - Nonautocorrelation

OLS Regression (M-E PDG)

$$IRI_i = \beta_0 + \beta_1 \cdot (SF_i + \omega_{SF_i}) + \beta_2 \cdot (FC_{Total_i} + \omega_{FC_{Total_i}}) + \beta_3 \cdot (TC_i + \omega_{TC_i}) + \beta_4 \cdot (RD_i + \omega_{RD_i}) + \varepsilon_i$$

$$IRI_i = \beta_0 + \beta_1 \cdot (SF_i) + \beta_2 \cdot (FC_{Total_i}) + \beta_3 \cdot (TC_i) + \beta_4 \cdot (RD_i) + \omega_{SF_i, FC_{Total_i}, TC_i, RD_i} + \varepsilon_i$$

$$IRI_i = \beta_0 + \beta_1 \cdot (SF_i) + \beta_2 \cdot (FC_{Total_i}) + \beta_3 \cdot (TC_i) + \beta_4 \cdot (RD_i) + \varepsilon_{Total\,i}$$

- The ε_{Total} is correlated with the regressors!!

  → Exogeneity assumption is not met

  → Biased estimates

IV Regression

- IV Regression

$$IRI_i = \boldsymbol{\beta X_i} + \varepsilon_i$$

$$\mathbf{X_i} = f(\mathbf{Z_i}) + \boldsymbol{\omega_i}$$

- Where $\beta = [\beta_0, \beta_1, \beta_2, \beta_3, \beta_4]$,

  $X_i' = [1, SF_i, FC_{Total\ i}, TC_i, RD_i]$

  Z_i' = exogenous variables

IV Regression

- IV Regression by means of 2SLS
  - Project Z_i on X_i
  - Run least squares using projection of X_i

$$\mathrm{IRI}_i = \boldsymbol{\beta}\hat{\mathbf{X}}_{\mathbf{i}} + \varepsilon_i$$

$$\hat{\mathbf{X}}_{\mathbf{i}} = \mathrm{f}(\mathbf{Z}_{\mathbf{i}})$$

→ $\mathrm{COV}[Z_i, \varepsilon_i] = 0$

→ Estimates theoretically are consistent and unbiased

Panel Data Models

- Data used for calibrating the IRI models constains
  - Cross-sectional observations
  - Time series observations

    → Panel Data

- Panel Data
  - Use time history of a pavement section as IV
  - Account for heterogeneity
  - Can use random-effects or fixed-effects approach

    → Assume differences is pavement sections can be captured by the intercept

Panel Data Models

- Fixed-Effects

$$IRI_{it} = D_i \alpha_i + \beta_1 \cdot (SF_{it}) + \beta_2 \cdot (FC_{Total\,it}) + \beta_3 \cdot (TC_{it}) + \beta_4 \cdot (RD_{it}) + \varepsilon_{Total\,it}$$

- Random-Effects

$$IRI_{it} = \beta_1 \cdot (SF_{it}) + \beta_2 \cdot (FC_{Total\,it}) + \beta_3 \cdot (TC_{it}) + \beta_4 \cdot (RD_{it}) + \mu_i + \varepsilon_{Total\,it}$$

Panel Data Models

- Joint SF-IRI Fixed-Effects

$$IRI_{it} = D_i\alpha_i + \beta_1(Age_{it})[\beta_5(PI_i + 1) + \beta_6(Precip_i + 1) + \beta_7(FI_i + 1)] + \beta_2(FC_{Total\,it}) + \beta_3(TC_{it}) + \beta_4(RD_{it}) + \varepsilon_{Total\,it}$$

Dataset for Model Estimation

Dataset for Model Estimation

- Instrumental Variables
  - plasticity index of the subgrade soils (PI)
  - average annual precipitation in in. (Precip)
  - frost index in ^{o}F (FI)
  - age of the pavement structure in years (Age)
  - gradation of the subgrade soil: material passing the 0.02 and 0.075 mm sieves (p02 and p075)
  - the thickness of the asphalt layer (h_{AC})
  - thickness of the granular base (h_{GB})
  - air voids (V_a)
  - asphalt binder content (P_b)

IRI Model Estimation Results

Parameter	*OLS*			*2SLS (*)*		
	Estimates	*Std. Err.*	*t-value*	*Estimates*	*Std. Err.*	*t-value*
Intercept	62.20624	1.741995	35.71	78.13714	2.970058	26.31
SF	2.001199	0.1310402	15.27	2.146696	0.2284858	9.40
FC_{Total}	25.95162	7.706787	3.37	92.30135	20.11166	4.59
TC	-0.0259187	0.0072146	-3.59	-0.0540003	0.0125006	-4.32
RD	13.73836	3.931941	3.49	-34.44903	8.071185	-4.27

(*) Using the 5 instrumental variables: PI, Precip, FI, Age, p075, p02, h_{AC}, h_{GB}, V_a, and P_b as instruments.

IRI Model Estimation Results

Parameter	*Fixed-Effects*			*Random-Effects*		
	Estimates	*Std. Err.*	*t-value*	*Estimates*	*Std. Err.*	*t-value*
Intercept	50.72208	1.905259	26.62	66.3422	3.443986	19.26
SF	3.952196	0.225123	17.56	3.60462	0.209945	17.17
FC_{Total}	31.78041	5.483793	5.80	34.24757	5.383947	6.36
TC	-0.00627	0.009474	-0.66	-0.00646	0.009031	-0.72
RD	-16.4796	4.85916	-3.39	-7.68146	4.622678	-1.66

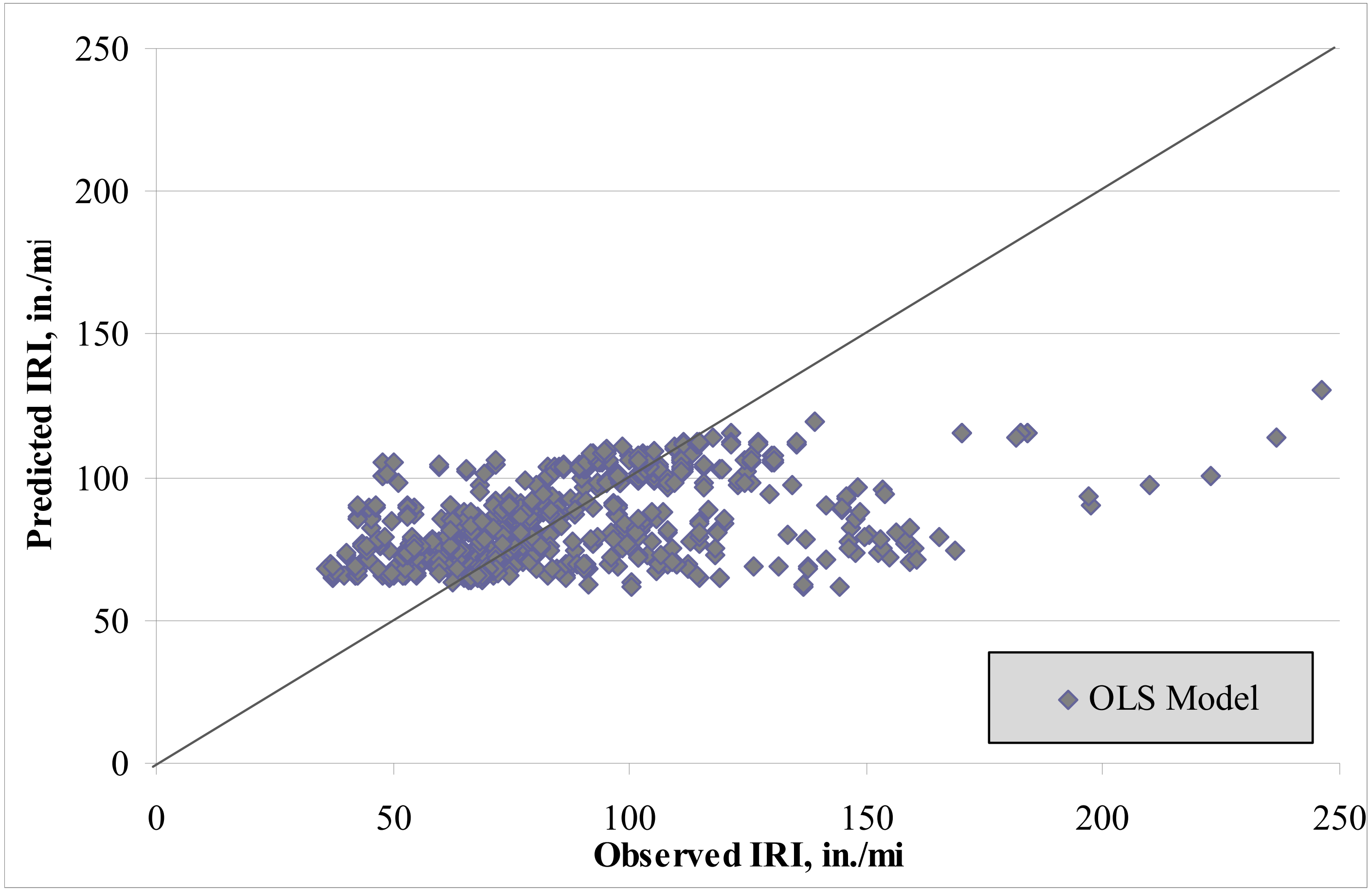
IRI Model Estimation Results

Parameter	*Joint Fixed-Effects*		
	Estimates	*Std. Err.*	*t-value*
Intercept	46.2979	2.040173	22.69
Age*(PI+1)	0.034418	0.013139	2.62
Age*(Precip+1)	1.473479	0.232363	6.34
Age*(FI+1)	0.001654	0.000195	8.47
FC_{Total}	22.133829	5.439472	4.07
TC	-0.016119	0.009425	-1.71
RD	-20.275383	4.644917	-4.37

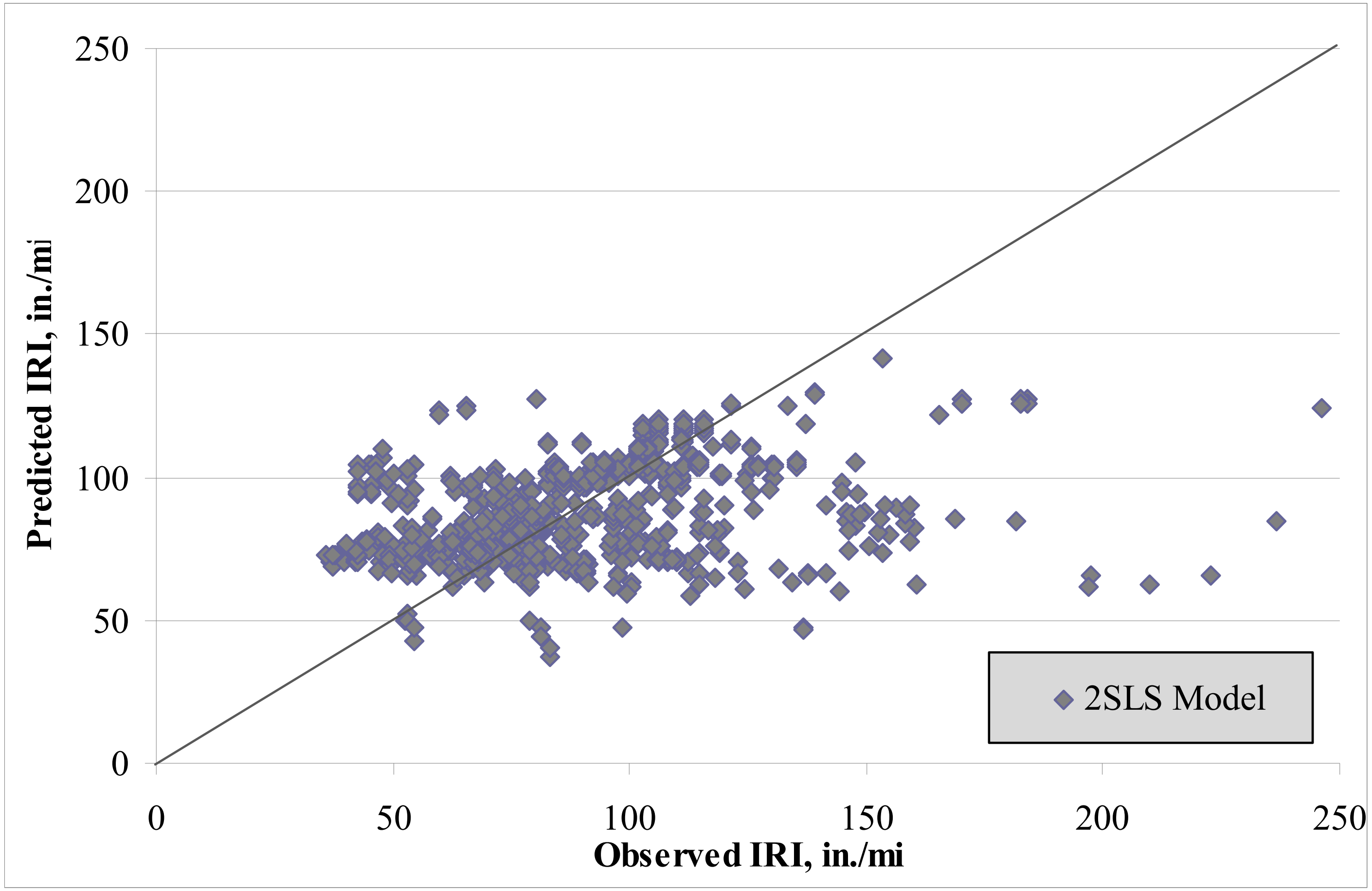
IRI Model Estimation Results

Estimate	*OLS*	*Instrumental Variable Regression*			
		2SLS	*Fixed-Effects*	*Random-Effects*	*Joint Fixed-Effects*
σ_ε	22.541	24.028	8.488	8.488	8.366
σ_u	-	-	35.398	30.291	34.605
$\sigma_w = \sqrt{\sigma_\varepsilon^2 + \sigma_u^2}$	-	-	36.401	31.458	35.602
R (**)	0.5150	0.4378	0.4831	0.4916	0.4895
F	119.18	105.37	163.32	164.78	118.40

IRI Model Estimation Results



IRI Model Estimation Results



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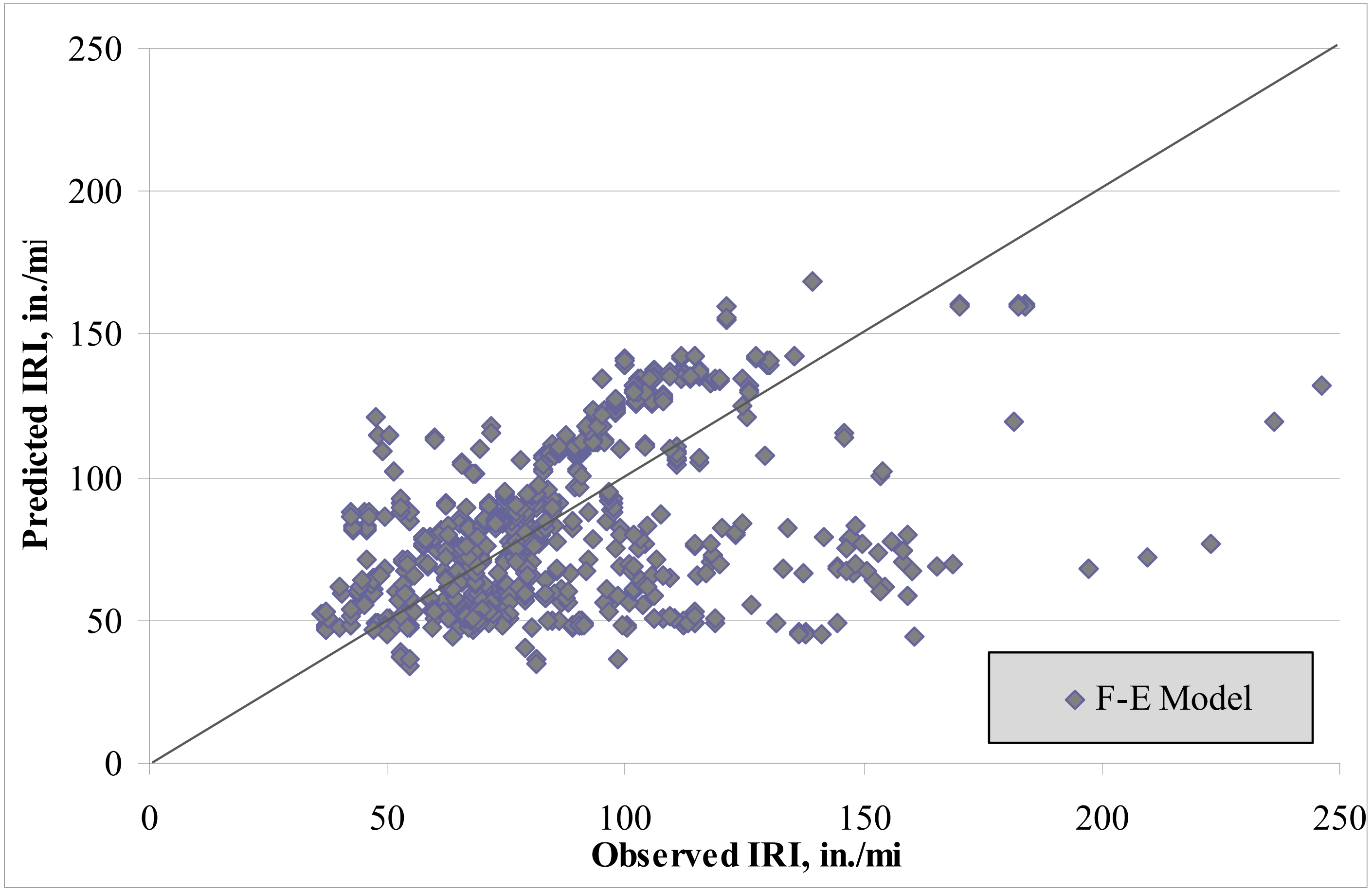

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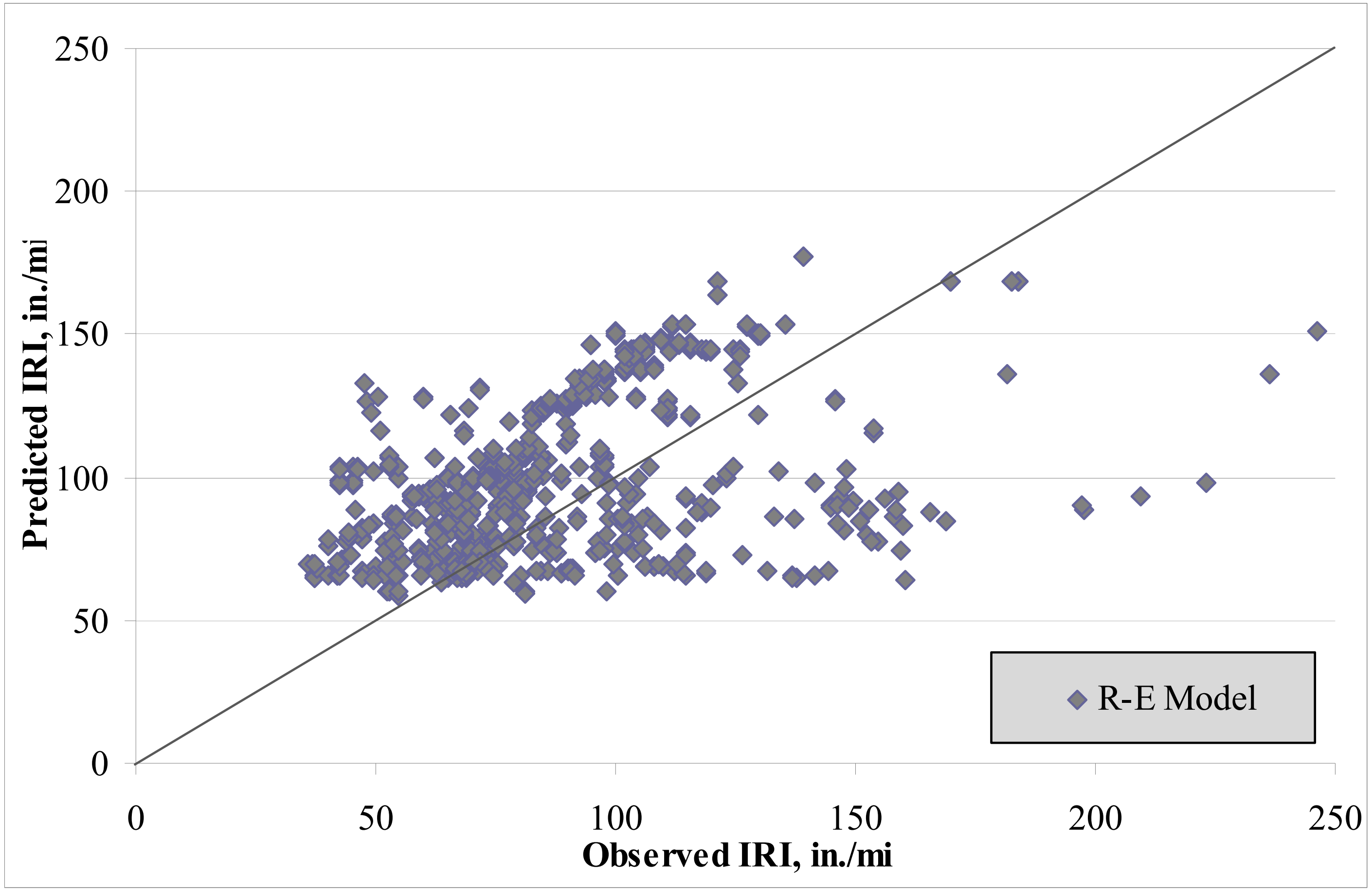

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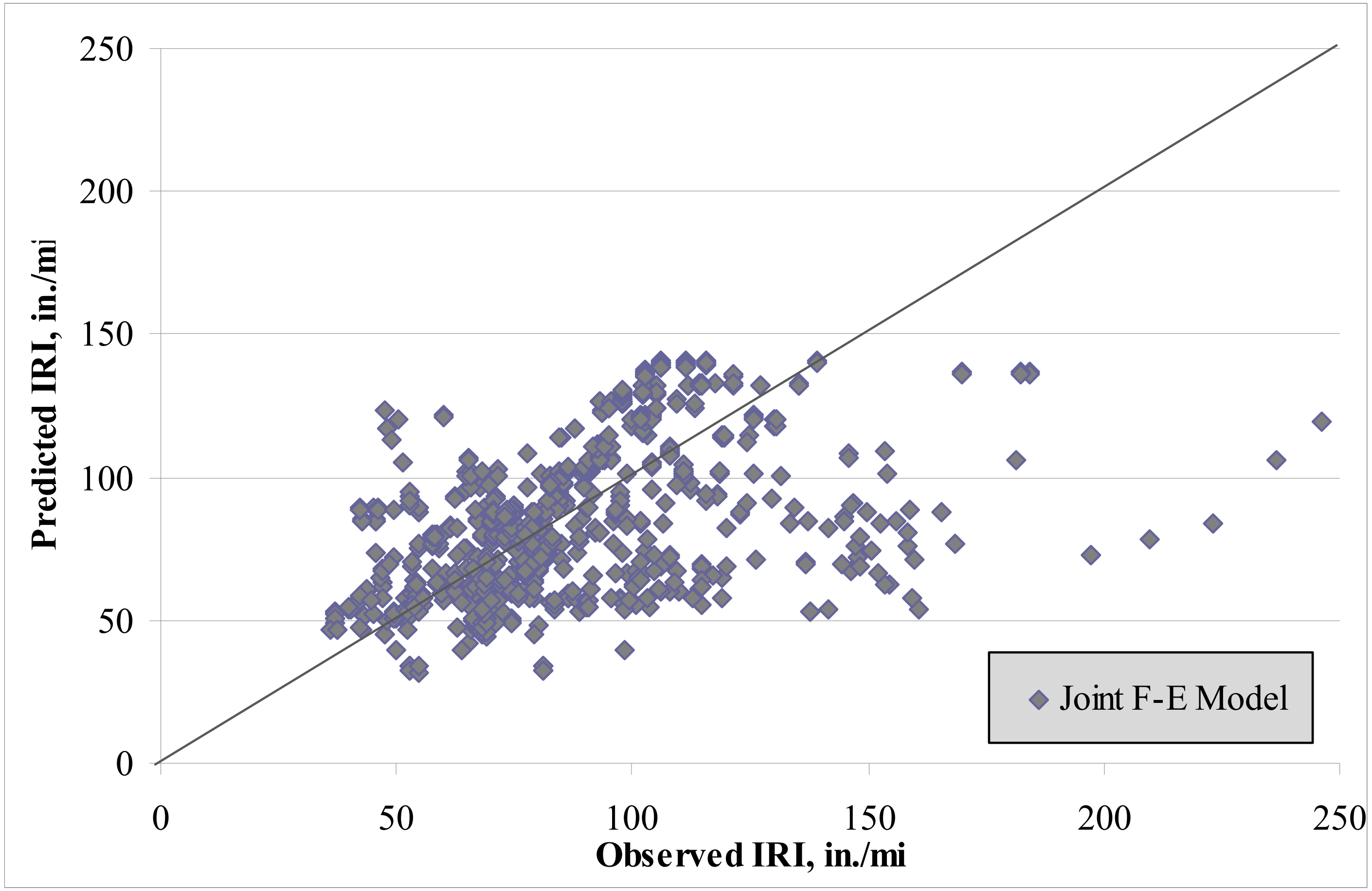

Improving on Flexible Pavement IRI Predictions
by Correcting for Possible Bias
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Conclusions

- Difference in estimates from OLS and IV Regression
  - → Endogeneity Bias
- S.E. for the panel data model increased
  - → Unobserved section specific attributes
- Panel Data Model parameter's are more significant (by means of F-stat)
- LM test (H_0: $\sigma^2_u = 0$) to test validity of pooled data models indicates there is bias due to unobserved variables

Conclusions

- A Hausman test indicated that the assumptions of the R-E Model are inappropriate
- The F-E and the joint SF-IRI F-E Models are preferred
- Observed changes (OLS vs. F-E):
  - an increase of 1 ft in the length of transverse cracks has increased IRI by 37.8%
  - an increase of 1 ft^2 in the area of fatigue cracking has decreased IRI by 14.7%
  - an increase in the rut depth of 0.1 in. is associated with a 24.8% decrease in IRI

Thank You

Questions ?

Comments ?