A Constant-Deflection Model for Road and Gravel Bicycle Tire Pressure: Empirical Calibration, Uncertainty Propagation, and Cross-Validation

Technical white paper of the BikeLab PSI Calculator

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June 2026 · v1.0 ·

Abstract

We present the physical–statistical model behind the BikeLab PSI Calculator. Its core is Frank Berto's constant-deflection criterion (15% tire drop), empirically fit as $P = 600 \cdot L/W^2 + 0.75 \cdot W - 25$ (±2 PSI within the measured domain: 20–220 lbs per wheel). Four contributions are introduced: (1) a re-anchored real-width correction regressed over 321 nominal/measured pairs from BicycleRollingResistance, showing that the classic rule anchored at 13 mm rims double-corrects what modern labeling (ETRTO 2020) already incorporates; (2) a front coupling $P_f = 0.93 \cdot P_r$ replacing static-load assignment, justified by braking load transfer and calibrated against SILCA and Rene Herse; (3) uncertainty propagation via Latin Hypercube Sampling (N = 10,000) yielding 90% confidence bands; and (4) a global sensitivity analysis (Sobol indices; 81,920 evaluations per case) refuting the hypothesis that load dominates the output: real width dominates on the road (S1 = 0.51–0.68) and gauge error on gravel (S1 = 0.61–0.73). Cross-validation over six configurations yields 9/12 wheels within ±10% of the average of both references; the three remaining deviations have identified physical causes and are documented rather than fitted away.

Keywords: bicycle tire pressure, 15% tire drop, Latin Hypercube Sampling, Sobol indices, ETRTO hookless, cross-validation

1. Introduction

Reference tools for bicycle tire pressure produce recommendations that differ by up to 20 PSI for the same configuration, declaring neither uncertainty nor objective function. SILCA optimizes impedance over professional athlete data; Rene Herse optimizes the comfort–speed balance with supple casings; manufacturer tables optimize legal liability. This work adopts a measurable, reproducible physical criterion — 15% constant deflection (Berto, 2004) — declares it, calibrates its corrections with auditable public data, quantifies output uncertainty, and publishes divergences against the references instead of hiding them.

2. Core formulation

For per-wheel load L (lbs) and real width W (mm), Berto's chart admits the empirical fit:

$$P = 600 \cdot L / W^2 + 0.75 \cdot W - 25 \text{ [PSI]}$$

with ±2 PSI accuracy within the empirical domain (20–220 lbs/wheel; 23–50 mm; 700C). The dominant L/W^2 term implies linear growth with load and quadratic decay with width — the physical root of the sensitivity result in §5. Per-wheel load derives from total system weight and geometry: racing 40/60 (front/rear), endurance 45/55, city/touring 35/65; only the rear load enters the formula (§3).

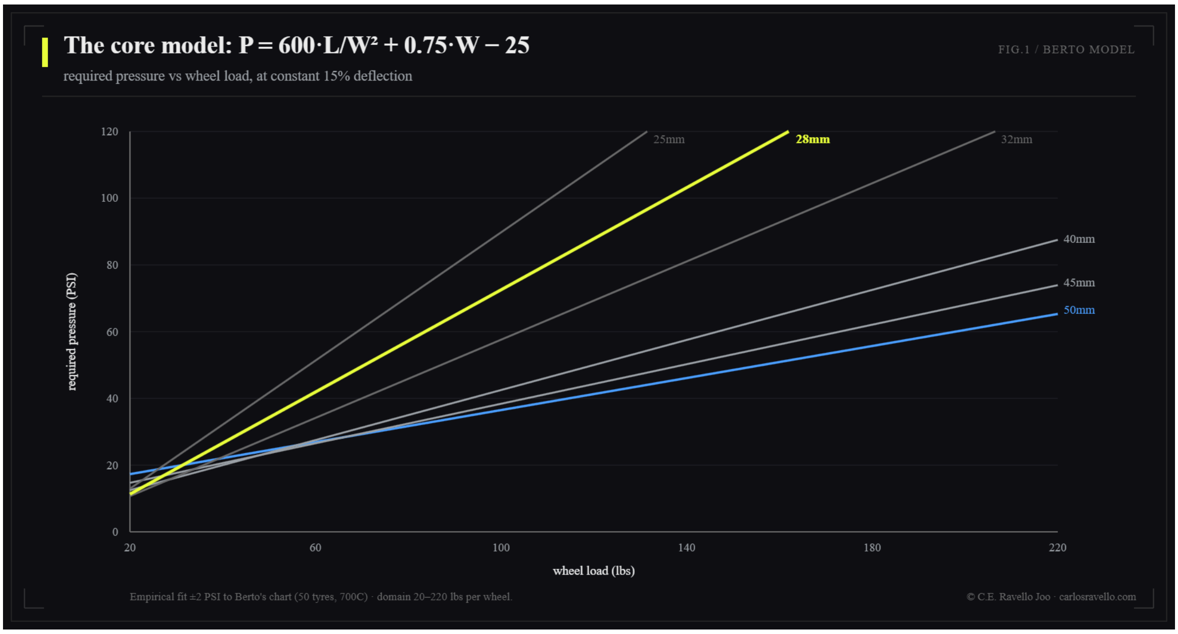

Figure 1. Family of P(L) curves by tire width; Berto's empirical domain shaded.

3. Front coupling

Static-load assignment to the front wheel yields fronts 24–36% softer than both references: a systematic failure. The cause is that under braking, mass transfer imposes front load peaks far above its static fraction; the references solve this without declaring it (SILCA: F/R differences ~2%; Rene Herse: single value). We adopt $P_{front} = k \cdot P_{rear}$ with $k = 0.93$, calibrated by sweep (0.86–1.00) against both references: simultaneous optimum in mean (3.8%) and maximum (8.0%) absolute deviation.

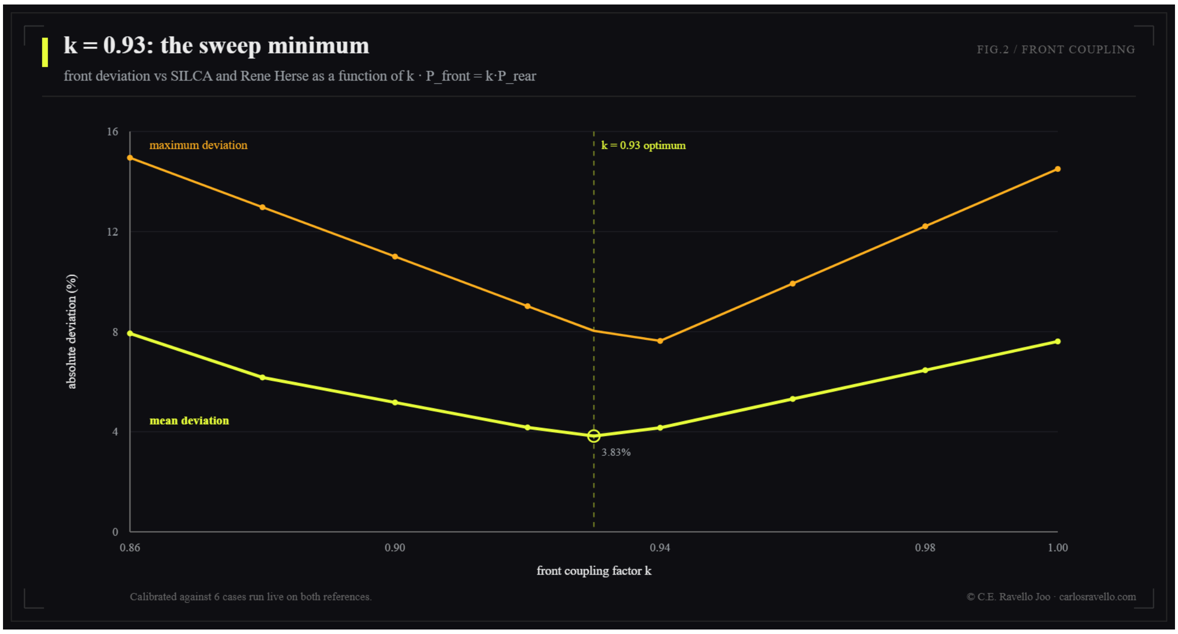

Figure 2. Calibration sweep of k; minimum at k = 0.93.

4. Real-width correction: the BRR census (n = 321)

The classic rule ($\Delta W \approx +0.4$ mm per mm of internal rim width above a 13 mm baseline) contains two independent claims: slope and anchor. The BicycleRollingResistance census (159 road tires on an 18.0 mm rim; 162 gravel tires on 17.8 mm; 2014–2026) validates the slope (direct two-rim measurement: 0.444 mm/mm; +11%) and refutes the anchor: measured $\Delta W = +0.82$ mm for road and -1.78 mm for gravel versus the predicted +2.0 mm. ETRTO 2020 specs modern nominals on 19–25 mm rims; the classic rule corrects twice what manufacturers already corrected. The re-anchored correction is $W = \text{nominal} + \delta(\text{cat}, \text{nominal}) + 0.4\cdot(\text{rim} - 18)$, with $\delta_{road} = 7.953 - 0.2727\cdot\text{nominal}$ (23–30 mm) and $\delta_{gravel} = 1.504 - 0.0827\cdot\text{nominal}$ (31–50 mm); residuals $\sigma = 0.94$ mm (road) and 1.34 mm (gravel). Direct caliper measurement replaces the whole chain ($\sigma = 0.5$ mm).

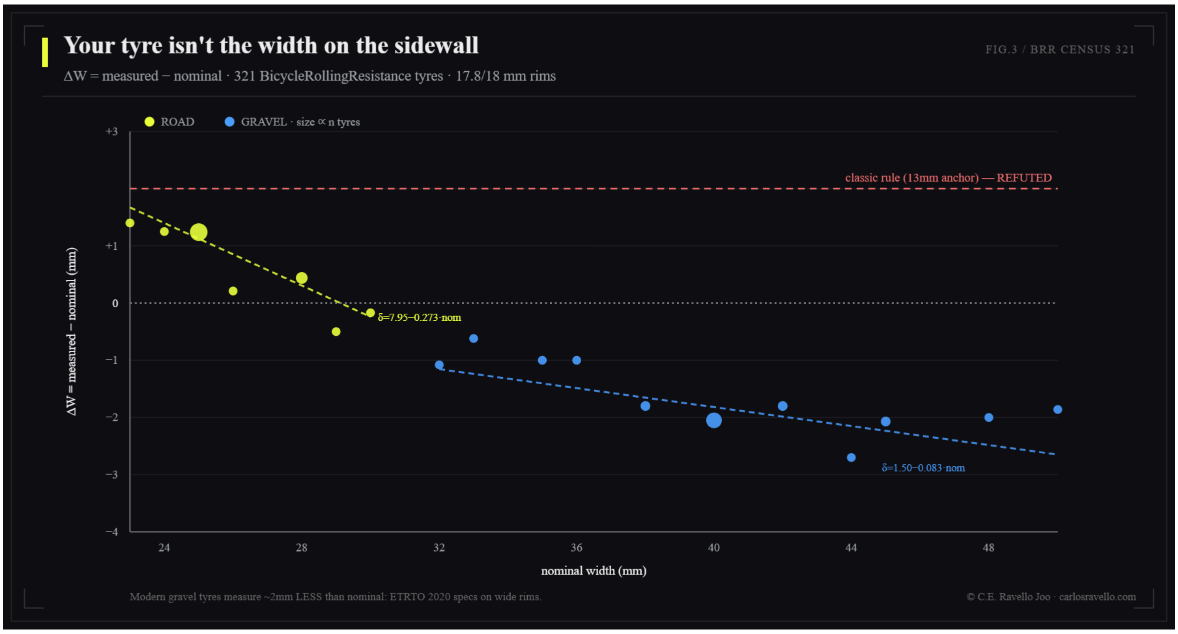

Figure 3. BRR census: ΔW by width class, per-category regressions, classic rule refuted.

Additional multiplicative corrections: butyl tube +5% (the classic +10% produced a +11.9% validation deviation); supple casing −5% / stiff +5% (Heine, 2020); rough asphalt −5%; gravel −12.5%. Caps applied last, without exception: hookless 72.5 PSI (ETRTO); hookless ≥30 mm internal, 60 PSI; 25 PSI warning floor.

5. Uncertainty (LHS) and global sensitivity (Sobol)

Uncertain variables: weight ~N(μ, 2 kg); real width ~N(W, 1.5 mm), or 0.5 mm with caliper; rear fraction ~U(±3 pp); gauge ~N(1, 5%) multiplicative. LHS with N = 10,000 per configuration (scipy.stats.qmc); Sobol via Saltelli scheme, base 2^13 (81,920 evaluations/case; SALib). The bands published by the tool exclude gauge error: it is the user's instrument uncertainty, not the model's.

Case	Configuration	Rear: mean [p5–p95] (PSI)	Dominant S1
1	83 kg · 28 mm · road · 21 mm	73 [63–86]	width 0.631
2	95 kg · 28 mm · road · 21 mm	84 [72–100]	width 0.650
3	75 kg · 32 mm · road · tube · 19 mm	63 [54–73]	width 0.512
4	85 kg · 40 mm · gravel · 24 mm	38 [35–41]	gauge 0.605
5	100 kg · 45 mm · gravel · 25 mm	39 [36–41]	gauge 0.726
6	70 kg · 25 mm · road · 21 mm	71 [59–85]	width 0.684

Table 1. 90% uncertainty bands (LHS, gauge excluded) and dominant Sobol index per case.

The design hypothesis — load dominates via L/W^2 — proves false: weight plus distribution explain <15% of variance in all cases. Real width dominates on road (S1 = 0.51–0.68; the ±5% width error enters squared) and the gauge on gravel (S1 = 0.61–0.73). S1 ≈ ST throughout: an additive model with no relevant interactions.

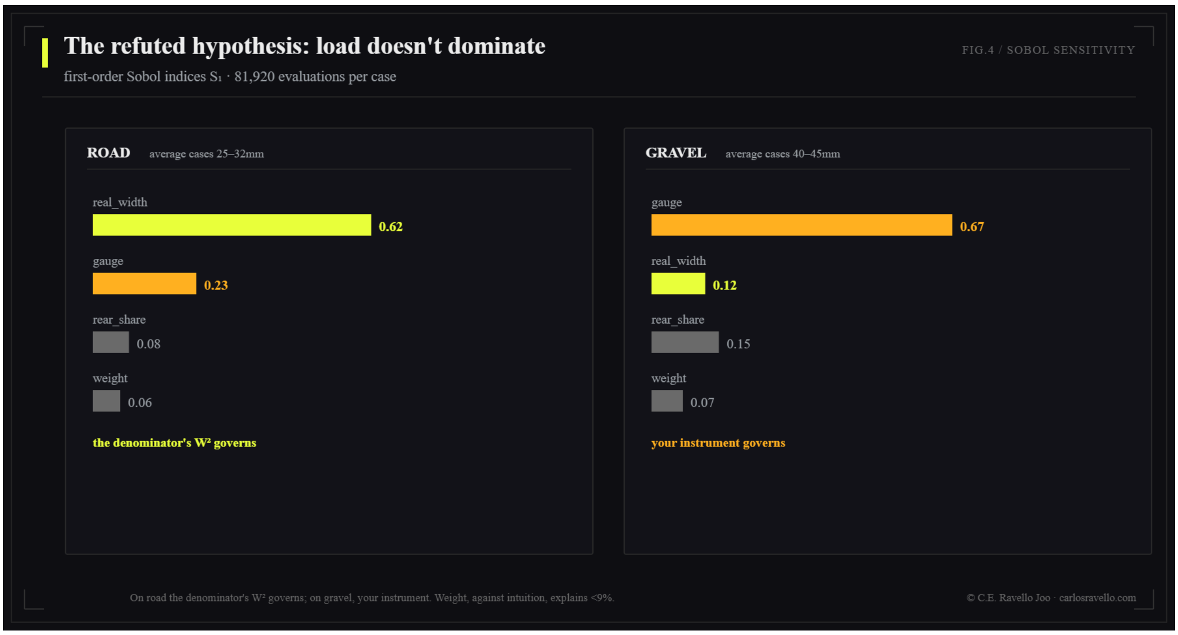

Figure 4. Sobol S1 indices per variable, road vs gravel.

6. Cross-validation

Six configurations executed live (June 2026) on SILCA and Rene Herse, with documented mapping of every parameter. Criterion: ≤10% versus the average of both references on road; widened tolerance on gravel (the references diverge by up to 30% from each other). Result: 9/12 wheels within criterion.

Case	BLS F/R	SILCA F/R	RH soft–firm	R dev.
1	68 / 73	70 / 71.5	54–67	+10.2%*
2	78 / 84	71.5 / 73.5	61–76	+17.9%†
3	58 / 62	63.5 / 65	46–57	+7.0%
4	35 / 38	34.5 / 36	34–42	+2.8%
5	36 / 39	29.5 / 30.5	35–43	+16.7%‡
6	65 / 70	80.5 / 83	55–72	–2.6%

*Table 2. Cross-validation (PSI). *Rounding artifact (references accept integer widths only). †Weight scaling, §6.1. ‡References diverge 30% from each other.*

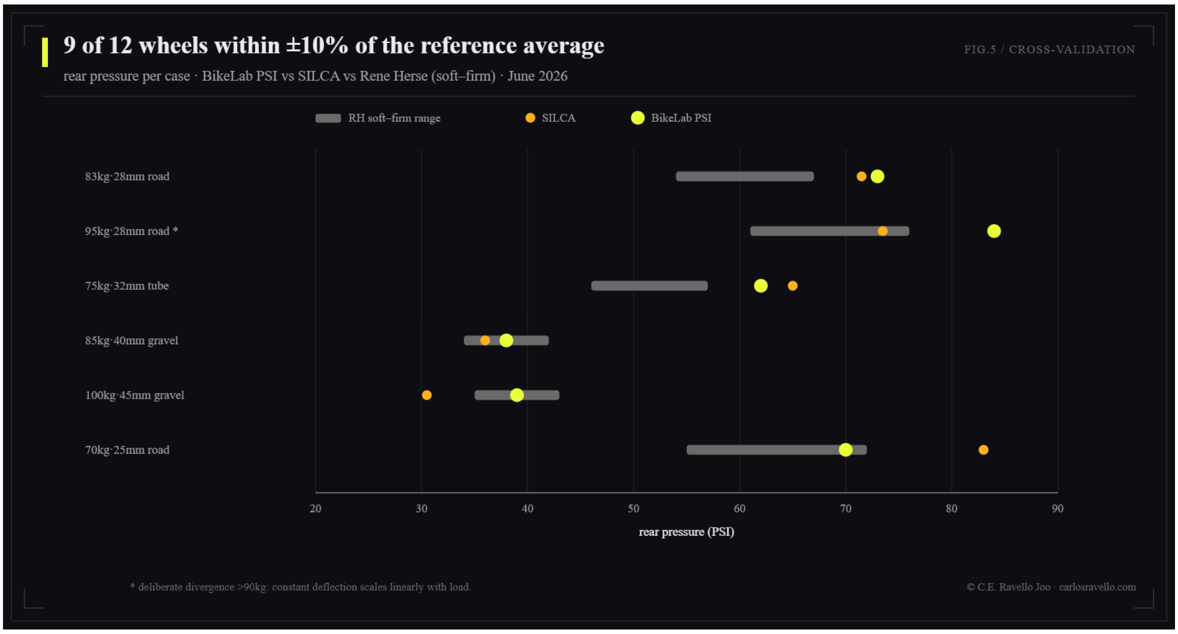

Figure 5. BikeLab PSI vs SILCA vs Rene Herse soft–firm range, per case.

6.1 Deliberate divergence for riders >90 kg

For riders over 90 kg the model recommends firmer pressures than SILCA. It is not a bug: constant deflection requires linear scaling with load; calculators that optimize impedance saturate with weight, those that optimize deflection do not. Case 2 loads 125 lbs on the rear — within Berto's measured domain (up to 220 lbs). In practice, the 72.5 PSI hookless cap compresses this divergence on most modern wheels.

7. Scope and limitations

(1) Berto measured with 1990s technology on 700C; the ±2 PSI belongs to the chart fit, not to every modern tire. (2) The casing correction discretizes a continuum into 3 levels. (3) k = 0.93 is calibrated against references that are themselves models. (4) The BRR census measures at standardized pressure; real width varies ~±0.5 mm with operating pressure. (5) MTB is explicitly out of domain: Berto declares the 15% criterion invalid for MTB (proportionally narrower rims, knobs distorting measurement, traction objective). (6) No true optimal pressure exists to validate against — only reasonable empirical philosophies; this model picks one, declares it, and publishes its uncertainty.

8. Reproducibility

Python 3.10; NumPy 2.2.6; SciPy 1.15.3 (qmc.LatinHypercube); SALib (Saltelli/Sobol); seed 42 + case id. The tool's JavaScript engine verified against the Python model case by case (exact match pre-rounding). BRR census captured on 2026-06-12 from the public tables at bicyclerollingresistance.com; raw datasets available on request. Tool: bikelabstudio.com/articles/psi-calculator-en.html (EN) and psi-calculator-es.html (ES).

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