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A power-based approach to model the impact of gradient in bicycle traffic simulation

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Introduction

- To simulate bicycle traffic, it is essential to capture how bicyclists react to features of the infrastructure, e.g., the longitudinal gradient of a bicycle path.
- Lack of modelling support for microscopic bicycle traffic simulation.
  - Bicycle traffic is often modelled by applying models that were originally designed for car traffic.
  - Car-based modelling approaches have limitations to simulate gradient effects on bicycle traffic (1).
- Bicycling requires human-powered motion, and the power output differs significantly among bicyclists due to physical capabilities and preferences.

We investigate the connection between gradient and power output in a population of bicyclists, towards developing a power-based modelling approach to simulate the bicycle traffic dynamics.

Site description and data collection

- **Location:** Lund, Sweden.
  - Weather: sunny with wind speeds of 5 m/s NE.
- **Type of infrastructure:** 140-m bicycle path segment.
  - 70% is on a bridge with maximum gradient of 5.2%.
  - Bidirectional traffic (separated from pedestrians/cars).
- **Data:** 40-min video of bicycle traffic, using a drone.
  - Off-peak period in a weekday in October 2020.
  - Trajectories extracted through manual and automated tracking tools.
  - Individual characteristics of bicyclists and bicycle cannot be observed in video.
  - Elevation map generated on site with theodolite.
  - In this study, only data of free-riding bicyclists (i.e., uninfluenced by surrounding traffic) are used: **107 bicyclists (65 riding uphill, 42 riding downhill)**.

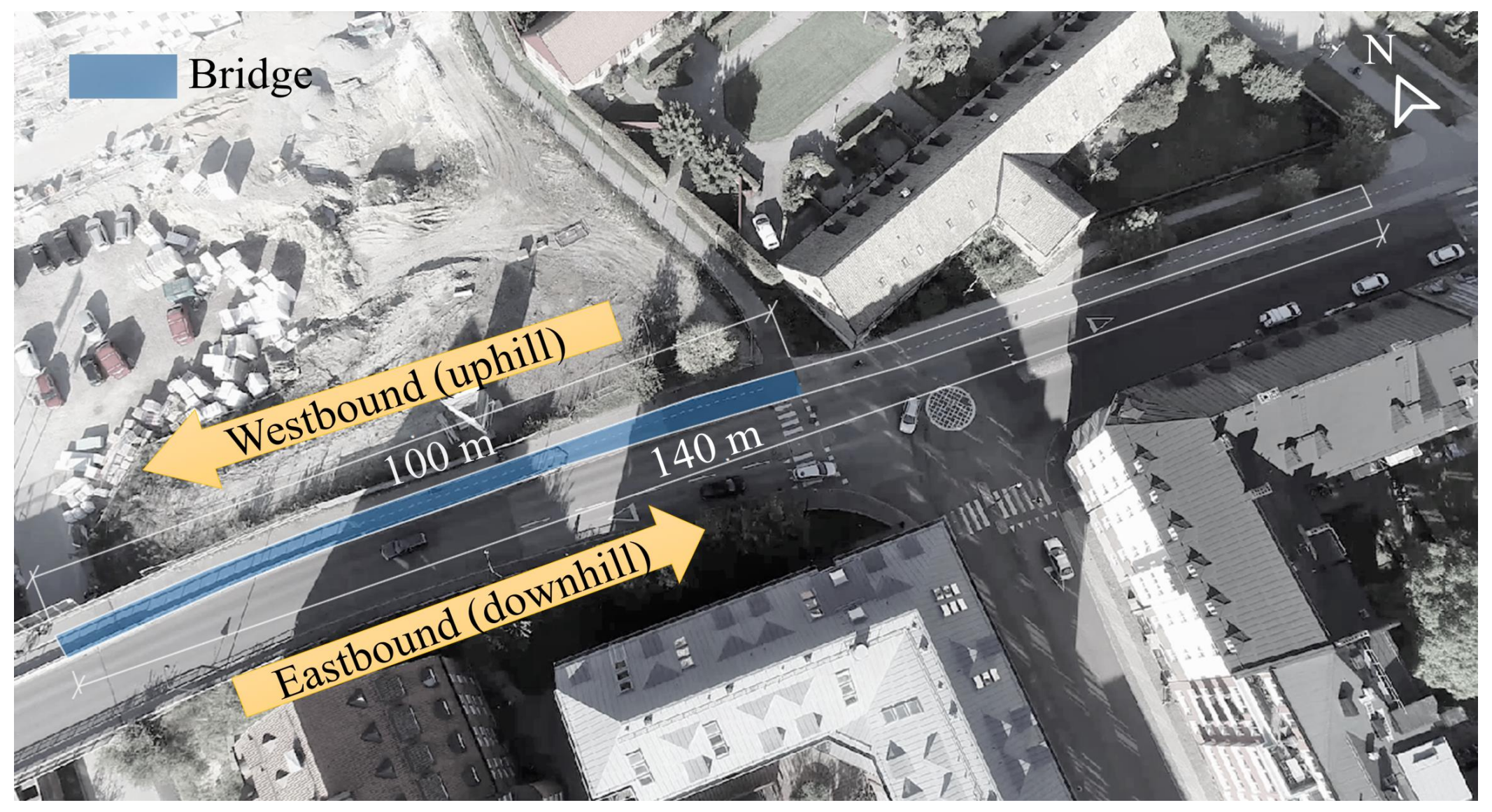
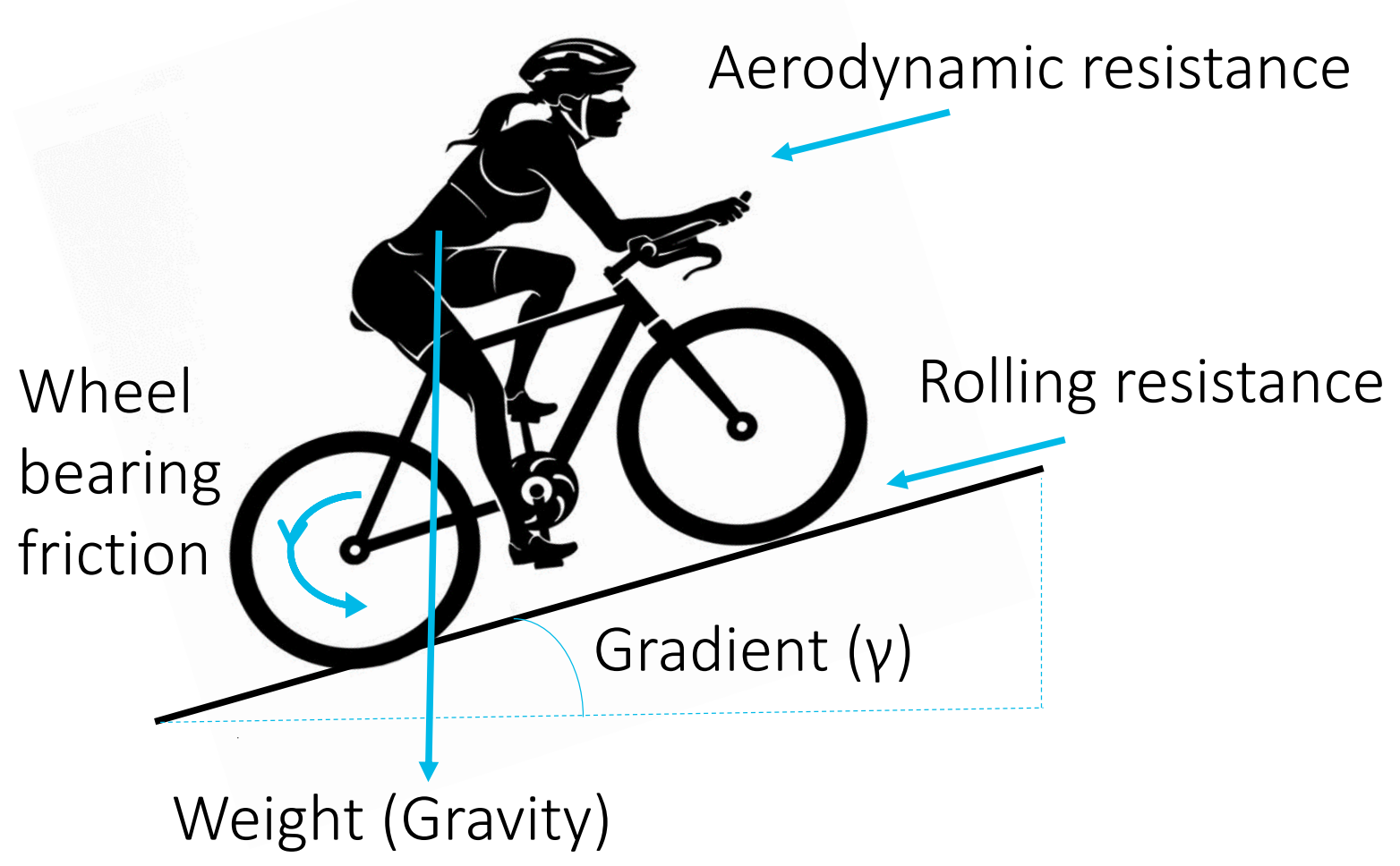


Figure 1. Aerial photograph of the observed bicycle path.

Bicycle dynamics

A mathematical model to estimate power output based on the conservation of energy (2).

- We estimate the **relative** change in power output based on trajectory data.



Impact of gradient in bicycle traffic

- Significant change in speed due to gradient.
- Diverse gradient impacts in bicycle traffic.

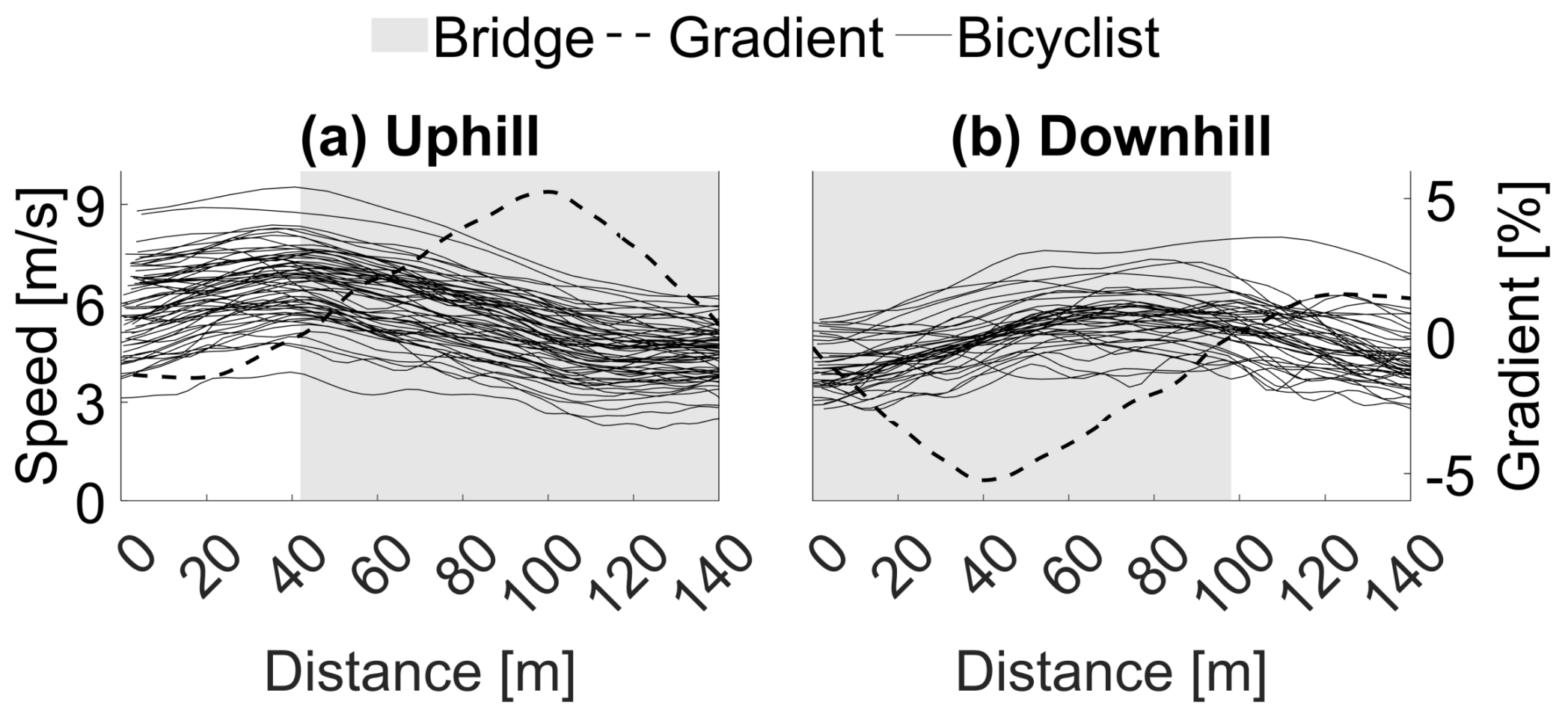


Figure 2. Observed smoothed speed profiles.

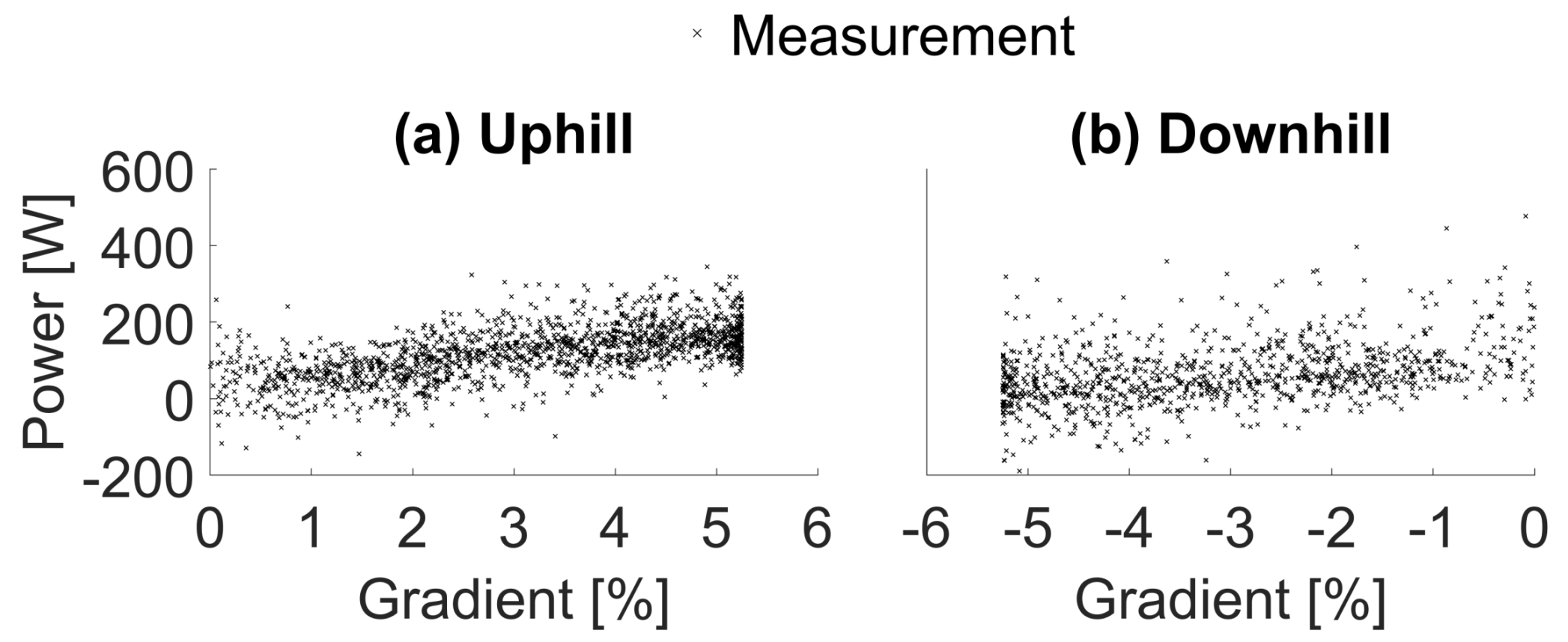


Figure 3. Estimated power output versus gradient.

Model estimation

A linear correlation between power output and gradient:

- On the uphill, bicyclists increase their power output as gradient increases to compensate for the loss in speed.
- On the downhill, bicyclists decrease their power output as gradient decreases due to braking and/or coasting.
- Variation in power output is explained by the gradient to a greater extent on the uphill than on the downhill.

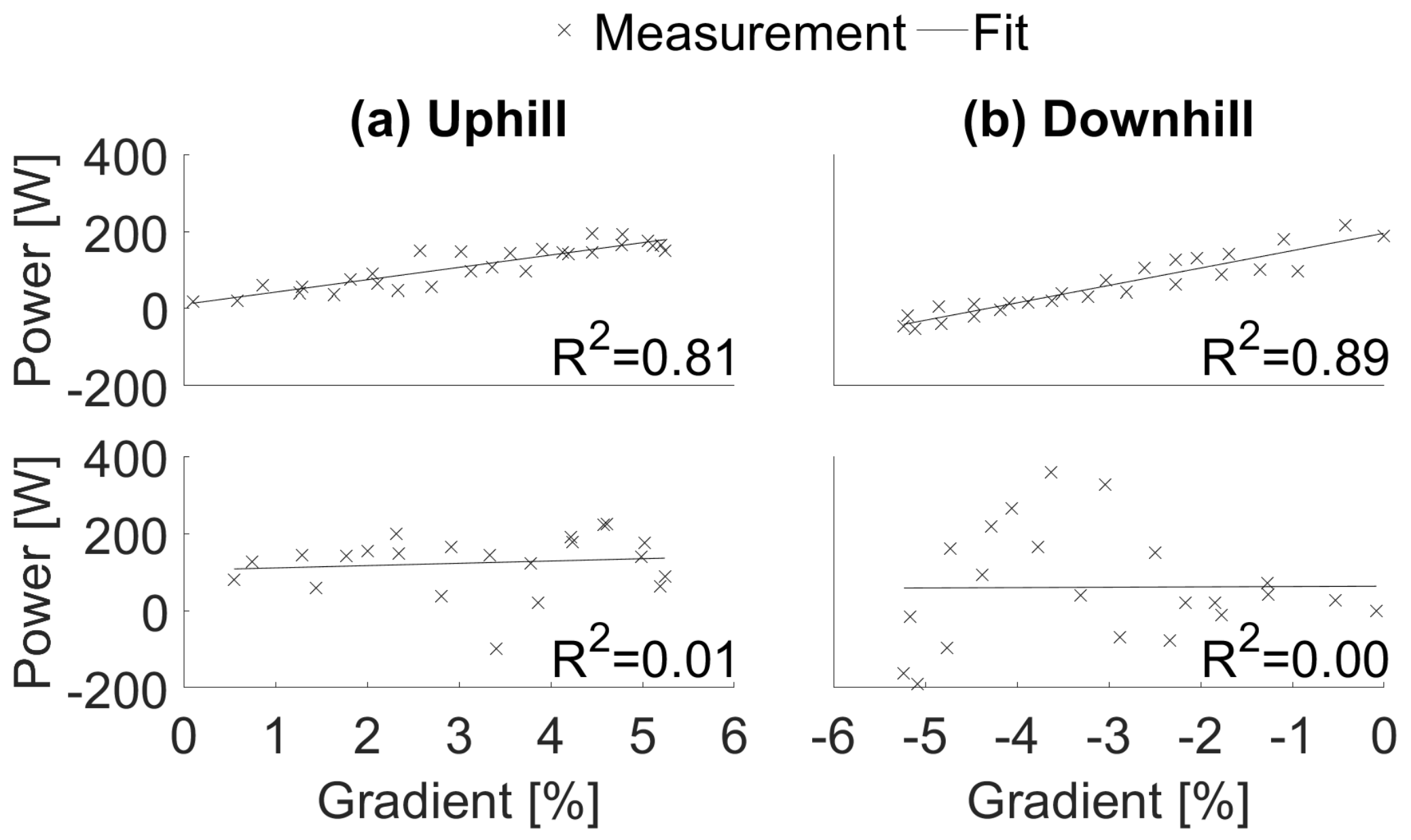


Figure 4. Estimated power output versus gradient for 4 bicyclists.

An **individual linear model (ILM)** for power output adaptation (p_{pedal}) as a function of gradient (γ):

$$p_{pedal} = p_0 + p_1\gamma$$

Where:

- p_0 : desired power output (to keep v_{des} when $\gamma = 0$).
- p_1 : desire (or ability) to compensate for γ.

- Distributions of p_0 and p_1 are sensitive to uncertainties in power output estimation (e.g., weight and aerodynamics).
  - Uncertainties do not significantly impact the ILM fit.

Simulation

- Using ILMs, we simulate gradient effects by conservation of energy.
- For most bicyclists, observed and simulated speed profiles are similar.
  - Estimation errors due to tactical behavior, and large oscillations in power output.

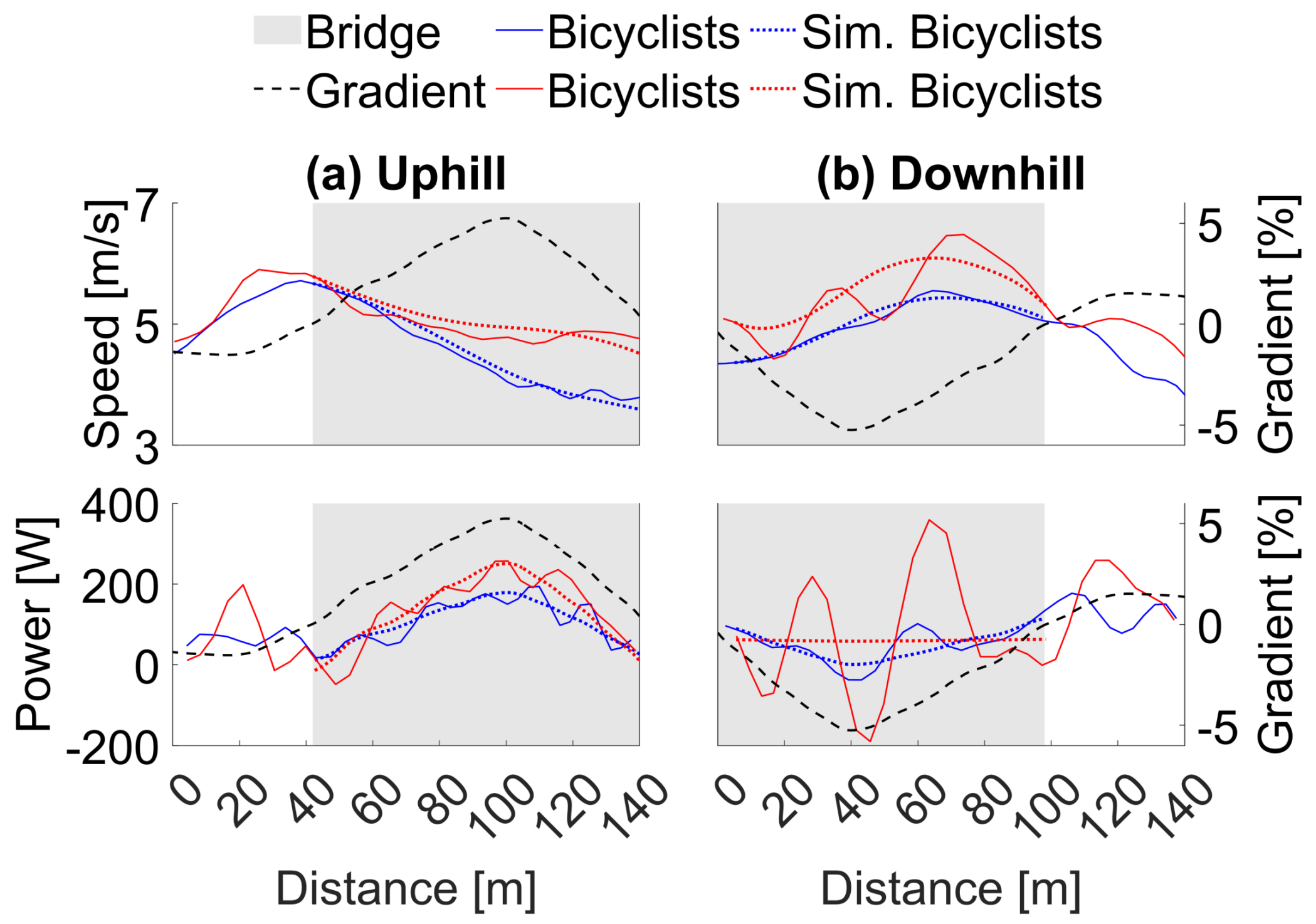


Figure 5. Simulated speed and power output profiles for 4 bicyclists. Bicyclists in blue illustrate accurate estimations of speed, and bicyclists in red illustrate poor estimations of speed.

- Maximum proportional in-sample error in estimation of speed is less than 10% for most bicyclists.
- Proportional in-sample error in estimation of total travel time is less than 5% for most bicyclists.

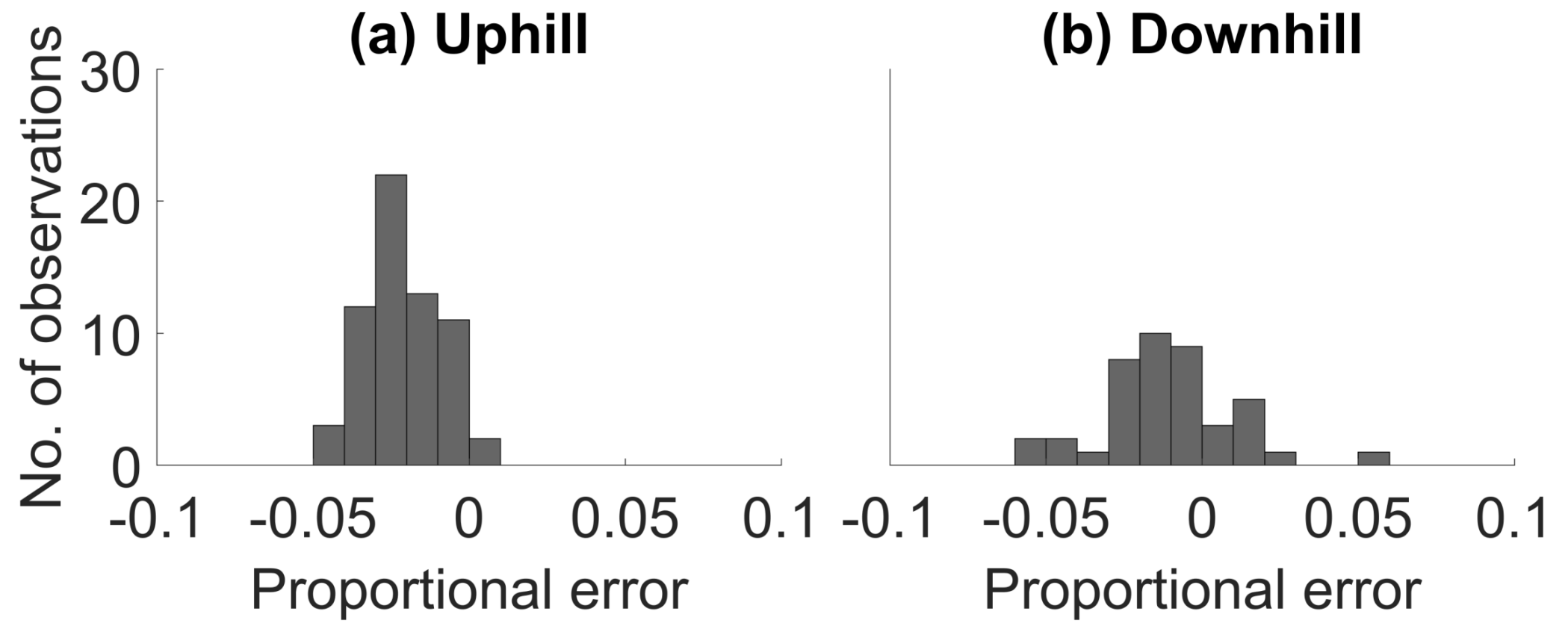


Figure 6. Histogram of proportional in-sample errors in estimation of total travel time for all bicyclists.

Conclusions

- The impact of gradient varies greatly among bicyclists.
- Cyclists adapt to compensate for the gradient.
- Simulation captures well the gradient impacts in a population of bicyclists by modelling power output as a linear function of gradient.
- A power-based model approach seems suitable for simulating free-riding in bicycle traffic.
- Future research includes:
  - determining the domain of applicability of the presented linear model,
  - investigating the impact of other elements of the infrastructure that affect free riding, and
  - investigating energy expenditure and effort as explanatory variables that trigger tactical behavior.

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