THE EFFECT OF STOCHASTIC VOLATILITY IN PREDICTING HIGHWAY BREAKDOWNS

Eric M. Laflamme, Plymouth State University, NH
and
Paul J. Ossenbruggen, UMass Boston
Breakdown Risk

\[ P(D_t > C) \]

- **Traffic demand:** \[ D_t = q_t \pm \sigma_t \]
- **Signal:** \[ q_t \]
- **Stochastic volatility:** \[ \sigma_t \]
- **Stochastic capacity:** \[ C \]
I-93 Salem, NH

near Salem — Rockingham

q03, Bottleneck

q02, No bottleneck
Stochastic Capacity

$q_0 = \text{maximum daily flow}$

Censored: $q_0 = 6000 \text{vph}$

Breakdown: $q_0 = 6000 \text{vph}$
Traffic Signal

Stochastic Capacity

\[ C \sim GEV(q_0; \alpha, \beta, \xi) \]

Stochastic Volatility

- **Challenge.** The role that noise plays is not fully understood. It is difficult to model because it is a hidden variable, changing with traffic demand and time.

- The noise complications the analysis as illustrated by the one-step ahead observations.
Stochastic Volatility

\( \sigma_t \) by time of day:

- An individual SV model was fit for each day.
A composite SV model was fit for all 205 days. 

\[ \sigma_t \] by time of day:
What Triggers Breakdown?

- Breakdown Risk Forecasting:
  1. The GEV model is derived from signal data only. Noise was ignored and treated as a nuisance variable.
  2. SV models suggest that demand and SV are connected.
  3. Reliability Analysis accounts for GEV and SV model effects.

- **Hypothesis**: The action by a driver or drivers can destabilize traffic and cause breakdown.

Breakdown Risk

\[ P(D_t > C) \]

The effect of introducing noise into our breakdown prediction is quite stark. When modeling the noise separately and combining it with a flow signal, the prediction of breakdown itself becomes very noisy; much noisier, in fact, than probabilities based on the raw flow data.

We observe that the SV-based predictions of breakdown are not smooth, but tend to fluctuate wildly, especially at known volatile times of the day (morning/evening commutes). This seems to be in keeping with the 'random' nature of breakdown occurrence, where breakdowns cannot be predicted based solely on demand.

CONCLUSION AND DISCUSSION

In this paper we have outlined a procedure to predict highway breakdowns based on flow values. The innovative part of our approach is the independent modeling of flow volatility through the use of a stochastic volatility model, a model form commonly used in economic time series analyses. Functional data analysis (FDA) is used to extract realistic flow values by time of day. These flow signals are combined with estimates of SV to produce component estimates of demand. In the end, when compared to estimates based on observed data, our estimation procedure yields dissimilar demands and ultimately dissimilar predictions of breakdown. We have simply introduced a procedure, but, going forward, a more thorough simulation-based study should be performed to evaluate the predictive ability of our approach. That is, many of our conclusions are based on visual analysis, and more thorough statistical testing of our model should be pursued. The application of our study is clear: estimation of probabilistic prediction of breakdown can be a valuable tool for decision-makers and administrators. At the very least, our results suggest that SV plays a minor role in forecasting traffic breakdown.
Conclusions

1. Breakdown risk w/o SV model forecasts are “smooth” over time of day.

2. Breakdown risk with SV model forecasts are “spiky” during rush. Can affect delay forecasts.

3. Monte Carlo simulations with “spiky” forecasts when averaged are similar to “smooth” forecasts from item 1.
Further Work

❖ **Driver Hypothesis**: “Smooth” forecasts tend to discredit the hypothesis.

❖ **Delay**: “Spiky” forecasts may explain why some breakdowns have extreme consequences.

❖ **Design Tool**: “Smooth” forecasts may be useful for evaluating design alternatives and in meeting long term reliability targets and tracking performance.