Bootstrap Variance Estimation in Industrial Prices

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U.S. DEPARTMENT OF LABOR

Outline

- Variance estimation background
- What is the bootstrap?
- Sampling methodology in PPI/IPP
- PPI/IPP examples
- Complications
  - Missing data
  - Maintaining replicates over time
- Pros and Cons of bootstrap
- Empirical-based confidence intervals
- Uses of variances / next steps

Variance estimation background

- Important measure of the precision of an estimate
- In general, we tend to focus on the accuracy of an estimate (e.g. coverage, response rates)
- We should be concerned about accuracy and precision (a.k.a. bias and variance which can be measured by the mean square error - MSE)
- Variance estimation is one of the major benefits of probability sampling

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Variance estimation background

- Variances estimates must be a function of the estimator of interest and the sampling design (Wolter, 1985)

- Industrial prices has the following:
  - Complex, multi-stage stratified sample designs with unequal weights
  - Non-linear estimators
    - Laspeyres price indexes with two different sets of weights (i.e. lower-level sampling weights and upper-level aggregation weights)
  - Longitudinal data

- Therefore, cannot use simple formulae

What is the bootstrap?

- Type of resampling method
  - Create subsamples for the estimate of interest from full sample
  - Calculate subsample (or replicate) estimates
  - Variation among the replicate estimates is used to estimate the variance of the full sample
  - Other examples - Jackknife, Random Groups, Balanced Repeated Replication (BRR)
  - Conceptually relatively easy

    (e.g. no complicated formula derivations, no covariance matrices, etc.)

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More on bootstrap

- First introduced by Bradley Efron (1979) for independent and identically distributed observations from some distribution
- Many different adaptations since to apply to variance estimation for survey sampling
- Rao and Wu rescaled bootstrap - Rao, Wu, and Yue (1992)
  - Used to handle stratified, multi-stage sampling designs
  - Justifies using a Simple Random Sample With Replacement (SRSWR) of PSUs
  - Applies a scale adjustment to the final survey weights to account for the variability of units selected at subsequent stages

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Some additional terminology

- Following the principle of ultimate clusters (Wolter, 1985)
  - That is, the aggregate of all elementary units selected from the same PSU is subsampled.
  - In other words, all second, third, and successive stage units selected from the same PSU are treated as a single unit.
- Particular care is required for self-representing (or certainty) PSUs
- Each certainty PSU should be treated as a separate stratum
- Variance strata = sampling strata for non-certainty units
  + certainty units
- Variance PSUs = units sampled within each variance stratum

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Bootstrap method

1. Independently in each variance stratum *h*, select a bootstrap sample by drawing a SRS of PSUs with replacement from the n_h sample PSUs. Let t_{hi} be the number of times that PSU *hi* is selected in bootstrap sample *b*.

2. For each secondary sampling unit (SSU) *k* in PSU *hi*, calculate the initial bootstrap weight by rescaling its initial sampling weight:

$$w_{hik}^{(b)} = w_{hik}\left\{\left(1-\sqrt{\frac{n_h^{(b)}}{n_h-1}}\right)+\sqrt{\frac{n_h^{(b)}}{n_h-1}}\cdot\frac{n_h}{n_h^{(b)}}\cdot t_{hi}^{(b)}\right\}$$

Bootstrap method

2. However, our bootstrap sample size is $n_h^{(b)} = n_h - 1$

Therefore,

$$w_{hik}^{(b)} = w_{hik}\left\{\left(1 - \sqrt{\frac{n_h^{(b)}}{n_h - 1}}\right) + \sqrt{\frac{n_h^{(b)}}{n_h - 1}} \cdot \frac{n_h}{n_h^{(b)}} \cdot t_{hi}^{(b)}\right\}$$

simplifies to

$$w_{hik}^{(b)} = w_{hik}\left\{\frac{n_h}{n_h - 1} \cdot t_{hi}^{(b)}\right\}$$

Bootstrap method

3. Calculate $\hat{\theta}^{(b)}$, the bootstrap replicate of estimator $\hat{\theta}$ by replacing the sample weights with the bootstrap weights in the formula of interest for $\hat{\theta}$ in each of the 150 bootstrap samples.

4. The bootstrap variance estimator of $\hat{\theta}$ is then given by

$$\hat{V}(\hat{\theta}) = \frac{1}{150}\sum_{b=1}^{150}\left(\hat{\theta}^{(b)} - \hat{\theta}\right)^2$$

This estimate is considered a Monte Carlo approximation of the bootstrap variance.

Why Monte Carlo Approx.?

- Consider the size of our sampling space. There are n^{n-1} possible bootstrap samples for each stratum.

- Therefore, even for small strata with 10 units.

  10^9 = 1,000,000,000 possible bootstrap samples

- We have 150 subsamples.

- When a sampling space (i.e. set of all possible outcomes) is so huge that it makes it impossible to work with all possible cases, results are obtained using a subset of that space at random; this is known as a Monte Carlo simulation.

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Sampling in PPI

- Sampling done by industry
  - Generally within a 6-digit NAICS
  - 600+ industries
  - Generally only one sample per industry is in the PPI at a time

- PPI uses a two-stage sample design
  - 1st Stage: A pps sample of establishments selected within each industry. The measure of size is typically employment.

  - 2nd Stage: Selection of items to be repriced from the first stage unit. Items should be selected proportionally to total revenue for the unit.

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PPI Example

NAICS 999999

NAICS 999999

							Number of times subsampled				
Establishment	Cert	Item	Cell	Adj. Item Weight	Bootstrap Adjustment	Price Relative	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Replicate 5
A	Y	1	a	50000	4/3	1.000					
		2	a	30000	4/3	1.010					
		3	b	12500	4/3	1.100					
		4	b	5000	4/3	1.050					
B	N	1	a	150000	3/2	1.035					
C	N	1	a	100000	3/2	1.025					
		2	b	50000	3/2	1.000					
		3	b	30000	3/2	0.950					
D	N	1	a	40000	3/2	1.200					
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$$cell\ rel. = \frac{\sum w_{hik}(pr)_{hik}}{\sum w_{hik}}$$

Cell a	1.0434					
Cell b	1.0068					

NAICS 999999

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$$cell\ rel.^{(b)} = \frac{\sum w_{hik}^{(b)} (pr)_{hik}}{\sum w_{hik}^{(b)}}$$

Cell a	1.0434	1.0830				
Cell b	1.0068	1.0055				

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		3	b	30000	3/2	0.950	1	2			
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$$cell\ rel.^{(b)} = \frac{\sum w_{hik}^{(b)} (pr)_{hik}}{\sum w_{hik}^{(b)}}$$

Cell a	1.0434	1.0830	1.0232			
Cell b	1.0068	1.0055	0.9849			

NAICS 999999

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B	N	1	a	150000	3/2	1.035	0	0			
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		3	b	30000	3/2	0.950	1	2	0		
D	N	1	a	40000	3/2	1.200	1	0	1		
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$$cell\ rel.^{(b)} = \frac{\sum w_{hik}^{(b)} (pr)_{hik}}{\sum w_{hik}^{(b)}}$$

Cell a	1.0434	1.0830	1.0232	1.0475		
Cell b	1.0068	1.0055	0.9849	1.0418		

NAICS 999999

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		2	a	30000	4/3	1.010	0	1	0	1	
		3	b	12500	4/3	1.100	1	0	0	1	
		4	b	5000	4/3	1.050	1	2	1	1	
B	N	1	a	150000	3/2	1.035	0	0	1	1	
C	N	1	a	100000	3/2	1.025	1	2	0	0	
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D	N	1	a	40000	3/2	1.200	1	0	1	1	
		2	b	20000	3/2	1.040	1	0	1	1	

$$cell\ rel.^{(b)} = \frac{\sum w_{hik}^{(b)} (pr)_{hik}}{\sum w_{hik}^{(b)}}$$

Cell a	1.0434	1.0830	1.0232	1.0475	1.0624	
Cell b	1.0068	1.0055	0.9849	1.0418	1.0600	

NAICS 999999

Establishment	Cert	Item	Cell	Adj. Item Weight	Bootstrap Adjustment	Price Relative	Number of times subsampled: Replicate 1	Replicate 2	Replicate 3	Replicate 4	Replicate 5
A	Y	1	a	50000	4/3	1.000	1	0	2	0	1
		2	a	30000	4/3	1.010	0	1	0	1	0
		3	b	12500	4/3	1.100	1	0	0	1	2
		4	b	5000	4/3	1.050	1	2	1	1	0
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Cell a	1.0434	1.0830	1.0232	1.0475	1.0624	1.0263
Cell b	1.0068	1.0055	0.9849	1.0418	1.0600	1.0191

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	Cell Weight	Full	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
Cell a	25,000,000	1.0434	1.0830	1.0232	1.0475	1.0624	1.0263
Cell b	15,000,000	1.0068	1.0055	0.9849	1.0418	1.0600	1.0191

NAICS 999999	1.0297	1.0539	1.0088	1.0454	1.0615	1.0191

- In future months, each cell will have its own replicate index value from which higher level calculations will be based

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	Cell Weight	Full	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
Cell a	25,000,000	1.0434	1.0830	1.0232	1.0475	1.0624	1.0263
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$$\hat{V}(\widehat{pr}) = \frac{1}{5}\sum_{b=1}^{5}\left(\widehat{pr}^{(b)} - \widehat{pr}\right)^2$$

Variance = 0.000479
S.E. x 100 = 2.18%

Sampling in IPP

- Two independent index series: Imports and Exports
- Sampling done by Harmonized Tariff Schedule of the U.S.
  - Product area based
  - Establishments may be selected for more than one product area
  - Panel approach: means multiple samples for a product area are in the index at a time
    - Two rotating panels each for imports and exports
    - Each panel made up of approx. one-half of the universe
    - One import and one export panel are sampled each year
    - Once initiated, a complete panel is repriced for 4 years

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Sampling in IPP

- IPP uses a three-stage sampling design within each panel
  - 1st stage: A pps sample of establishments selected within each broad product area (sampling stratum). The measure of size is the total dollar value of trade.
  - 2nd stage: Within each selected establishment-stratum detailed product categories are selected using a systematic PPS design. The measure of size is relative dollar value of trade.
    - These units are called Sampling Classification Groups (SCGs)
    - SCGs may be selected more than once
  - 3rd stage: Selection of items within establishment-SCGs to be repriced. Items ideally should be selected proportionally to the relative dollar value of trade.

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IPP Example

Imports HS 0199

HS 0199

							Number of times subsampled				
Establishment	Cert	Item	SCG	Sample Adj. Item Weight	Bootstrap Adjustment	Price Relative	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Replicate 5
A	Y	1	a	50000	2	1.000					
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$$cell\ rel. = \frac{\sum w_{hik}(pr)_{hik}}{\sum w_{hik}}$$

CG a	1.0434	1.0508	1.0225	1.0516	1.0593	1.0245
CG b	1.0068	1.0083	0.9840	1.0425	1.0425	1.0017

HS 0199

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HS 0199

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CG b	15,000,000	1.0068	1.0083	0.9840	1.0425	1.0425	1.0017
	HS 0199	1.0297	1.0349	1.0081	1.0482	1.0530	1.0159

$$\hat{V}(\widehat{pr}) = \frac{1}{5}\sum_{b=1}^{5}\left(\widehat{pr}^{(b)} - \widehat{pr}\right)^2$$

Variance = 0.000314
S.E. x 100 = 1.77%

Sample Design Matters!

- Similar data but different variance estimates

- Different sample design assumptions lead to different replicate estimates and variances

Complications

- Missing Data
  - Imputation should be done using the same methodology as the full sample but performed independently by replicate
    - Different subsamples will yield different imputations
- Maintaining replicates over time (very important!)
  - Longitudinal surveys chain monthly samples together to form longer term estimates. Therefore, same principle applies to the subsamples.
  - So, generally the bootstrap sample is the same for the current month as the previous month. Any new PSUs are given an opportunity to be added to each subsample.
    - This updating method could potentially cause a bias if new PSUs price trends are significantly different from the older PSUs. However, we believe any potential bias would be extremely small. (This needs more research.)

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Pros/Cons of Bootstrap

PROS	CONS
Easy to compute and understand	Computationally intensive
Flexible -- especially given many different tree structures in IP	Somewhat difficult to maintain replicates over time
Large number of degrees of freedom even for small strata	Not a balanced design
Better understanding of the sampling distribution -- empirical based confidence intervals	

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Confidence Intervals

- Typically, when 95% confidence intervals are calculated:

$$\hat{\theta} \pm z_{\alpha=.05} SE(\hat{\theta})$$

$$\hat{\theta} \pm 1.96 SE(\hat{\theta})$$

- This means that if the same sampling plan was drawn from the same population 100 times, then about 95 of the intervals would contain the true value.

- However, this assumes that the population is normally distributed.

Empirical Confidence Intervals

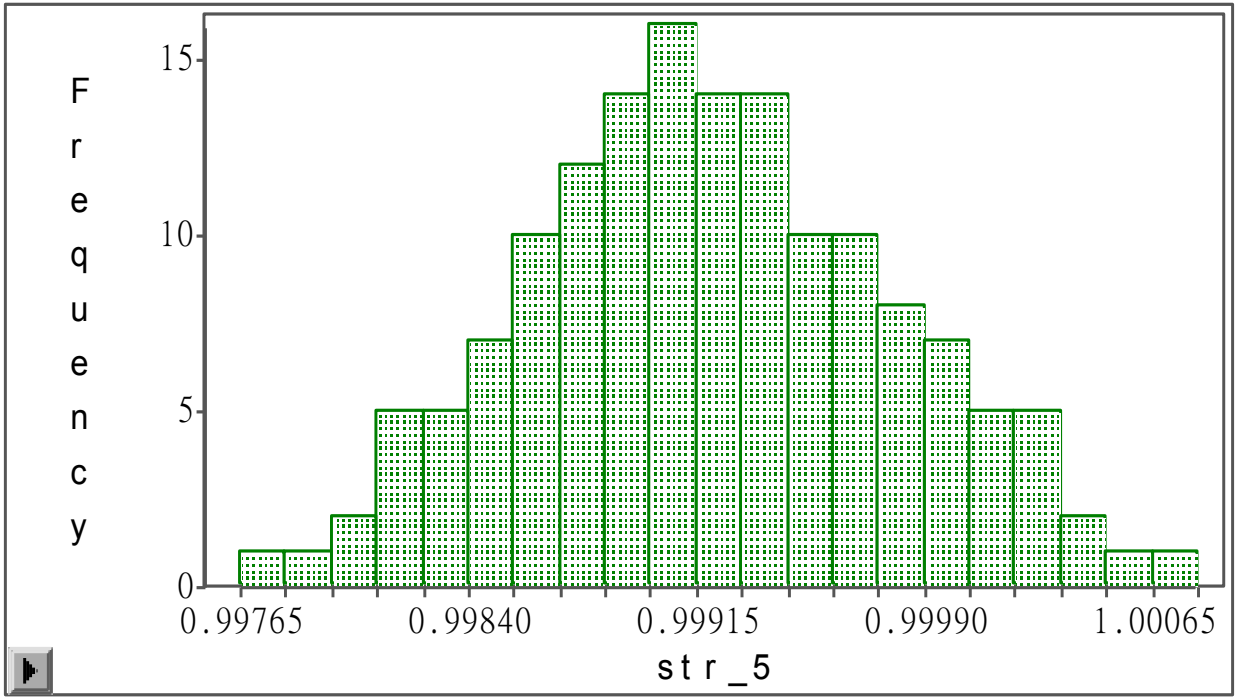
- There are 150 bootstrap samples. So, we can begin to get a picture of the sampling distribution.

- To calculate empirical-based confidence intervals
  - Sort the bootstrap replicates
  - For a 95% confidence interval, take the bottom and top 2.5% of the replicate estimates
    - Lower bound = 3.75 replicate estimate
    - Upper bound = 146.25 replicate estimate

BLS

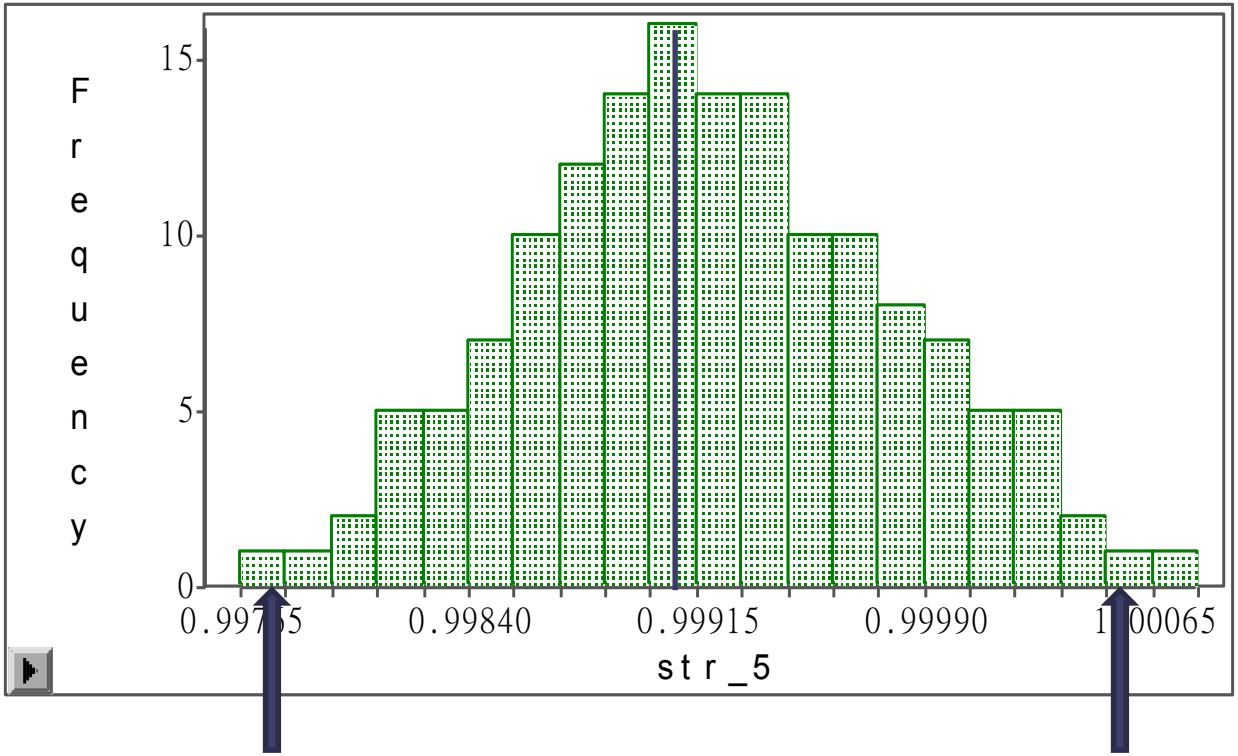
HTS XI – Textile and textile articles
(Imports July 2012)

-0.01%, SE=.074



HTS XI – Textile and textile articles
(Imports July 2012)

-0.01%, SE=.074



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HTS XI – Textile and textile articles

(Imports July 2012)

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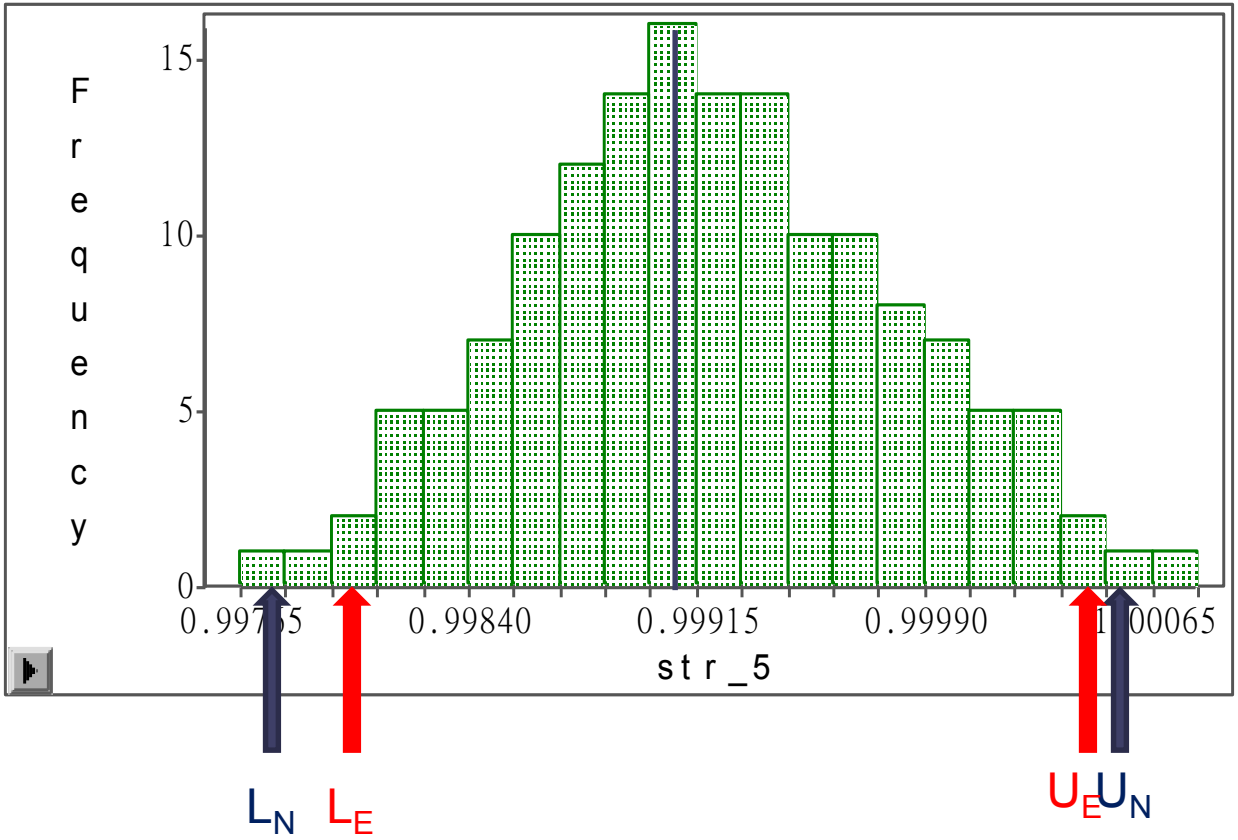
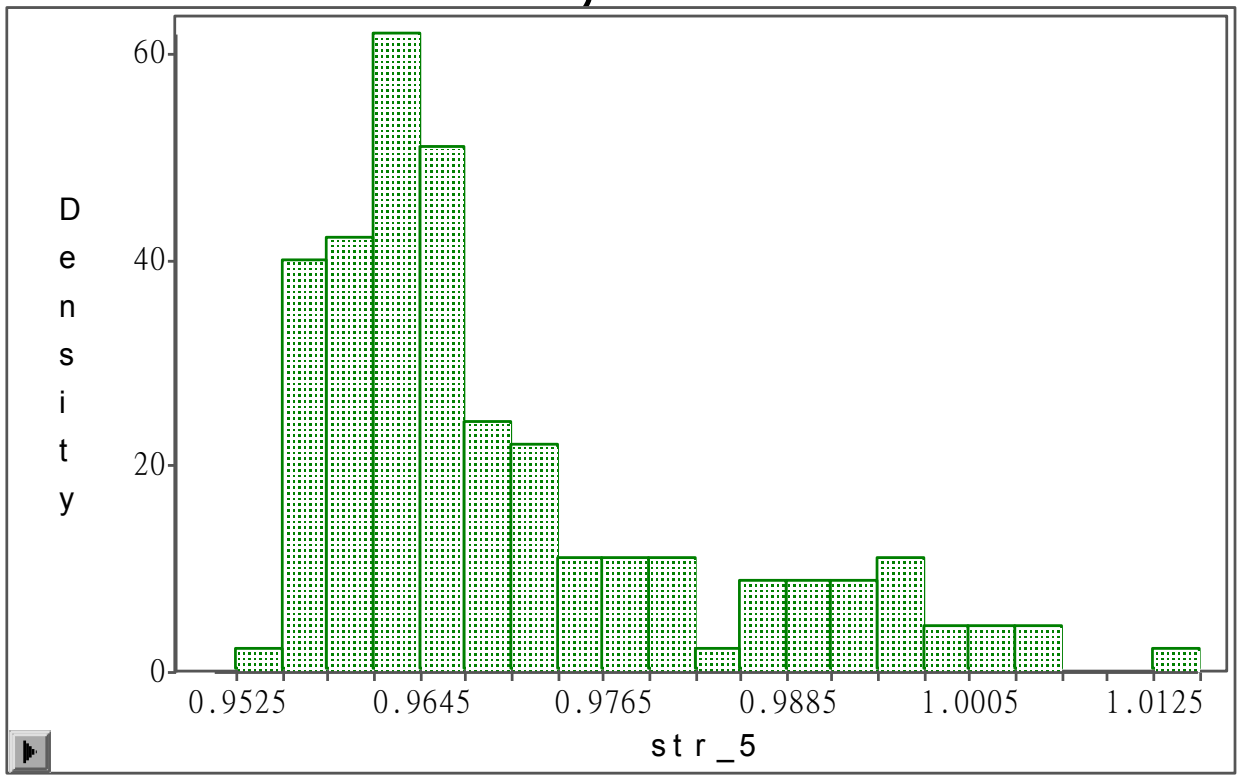


HTS II –Vegetable products
(Imports July 2012)

-3.46%, SE=1.458



HTS II –Vegetable products
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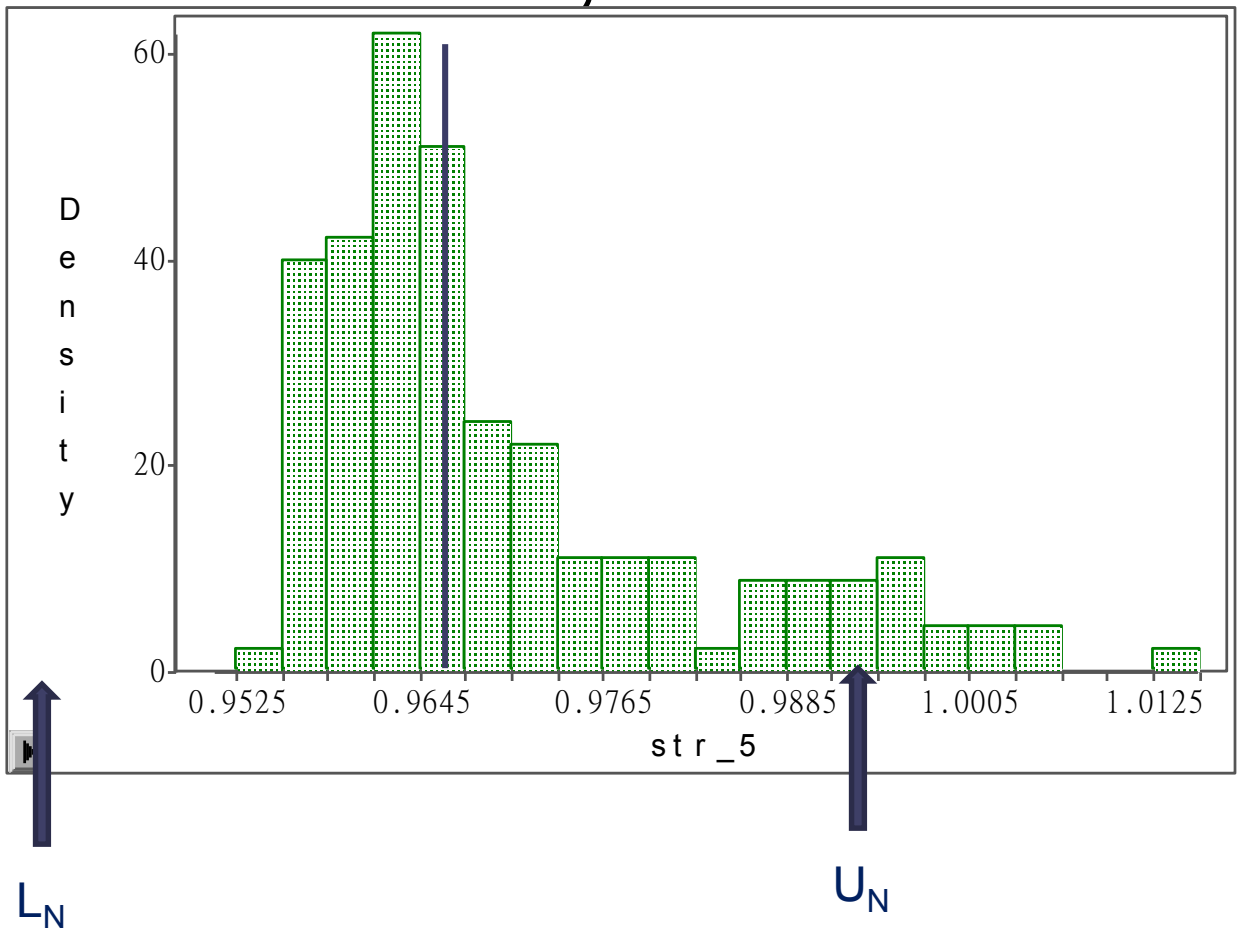

HTS II –Vegetable products
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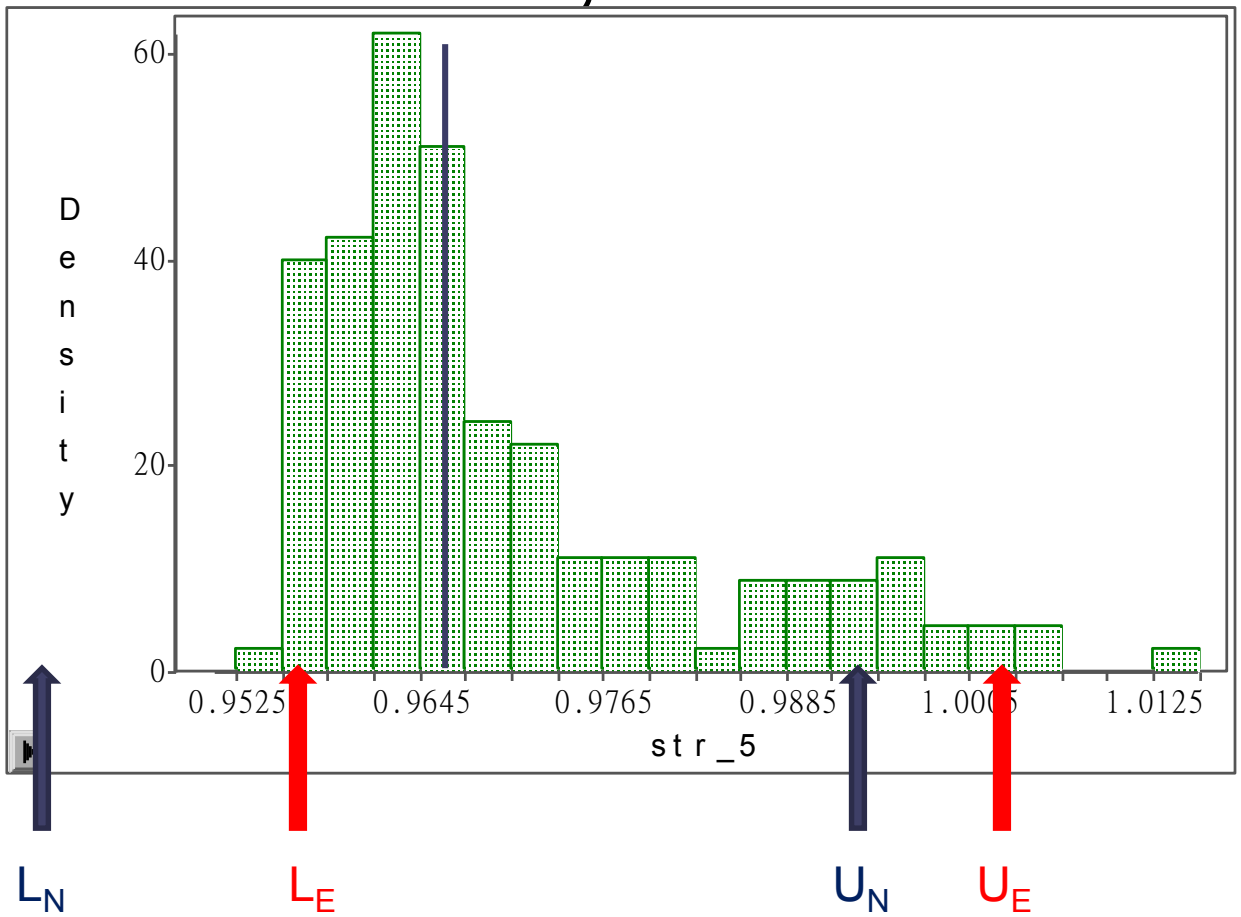
-3.46%, SE=1.458



How will variances be used?

- Publish an important measure of precision
  - Full disclosure as federal survey program
  - Allows users to make statistical comparisons (i.e. hypothesis tests)
- Sample allocation
  - Determine a more efficient sampling scheme
- Useful for index review
  - Identifying potential outliers or extreme data
- Refine index publication criteria

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