Precision in the Time Product Dummy Price Index: What happens when goods are sold in only a few periods?

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Summary

There is much to recommend the Time Product Dummy (Fixed Effects) index method: it is more general than the traditional hedonic regression that uses product attributes to control for quality change, it does not require analysts' judgment on which attributes to include (or the attributes data), and it controls for unobserved heterogeneity across goods that can affect price. But the use of good-specific fixed effects to control for quality differences across goods has raised questions about the usefulness of the resulting estimates.

One of the issues that has been raised is the possibility that high product churn (the fact that goods are typically not sold in all periods) leads to potentially unreliable parameters (deHaan, 2025). If goods are sold in very few periods, the good-specific dummy variables are likely to be highly correlated, a collinearity problem that could inflate the standard errors for the regression parameters. We argue that although collinearity in the fixed effects might translate into inflated standard errors for the fixed effects coefficients, it will not necessarily inflate the standard errors for the time dummy coefficients. It is the latter coefficients that are the parameters of interest for the construction of the TPD price index.

We apply collinearity diagnostics to two data sets. Using consultancy estimates for smartphones, we confirm a problem with the fixed effects that does inflate the standard errors of those coefficients. But that problem does not affect the time dummy coefficients. Using scanner data for desktop computers, the diagnostics for the time dummy coefficients point to a mild collinearity problem, but those coefficients have small standard errors and appear precisely estimated.

Fixed effects regressions (TPD)

The Time Product Dummy price index has been used as an alternative to the traditional time dummy hedonic (TDH) method

- Price index literature (CPI manual)
  - Shown to be more general than TDH
  - Important to use WLS with expenditure shares as weights
- Fixed Effects literature (Woolridge)
  - TPD can have a precision problem, but it won't necessarily affect the time dummy coefficients
  - The problem is related to how many periods each good is sold
  - Using the demeaned specification reduces the problem.

This paper views the precision issue as a collinearity problem

- Applying diagnostics to the time dummy coefficients in two datasets finds no collinearity issue in one and only a slight issue in the other.

Need more work to explore the pervasiveness and numerical importance of this problem.

Time Product Dummy regression and collinearity

Usual specification: $ln\, p_i^t = \alpha + \sum_t \delta^t D^t + \sum_i \gamma_i D_i + \varepsilon_i^t$

D_i =1 if the observation relates to good i and zero otherwise, i={2,…N)
D^t=1 if the observation relates to time t and zero otherwise, t={2,…T)
Remove a reference observation to prevent perfect collinearity (1,1).

There is a collinearity problem when correlations among the explanatory variables in a least squares regression inflate coefficients' standard errors.

Intuition: if observations per good is low, the columns with the good-specific dummies will tend to be highly correlated

Question:

When does collinearity affect the time dummy coefficients used to form deflators?

Diagnostic tool to identify whether time dummy coefficients are affected by collinearity (Belsley, Kuh and Welsch)

Variance Inflation Factors (VIFs) measure the degree of correlation among explanatory variables in a least squares regression. For the TPD, there is a VIF for each of the δ^t's and γ_i's that is calculated using:

$$VIF_i = 1/(1-R_i^2) \geq 1$$

where R_i^2 is the R^2 from a regression of X_i on all other X's.

Rule of thumb used in the literature:

- VIF = 1: coefficient not involved in a collinear relationship
- $1 <$ VIF < 5: moderately correlated.
- $5 \leq$ VIF < 10: require further investigation, and
- VIF ≥ 10 sign of serious collinearity.

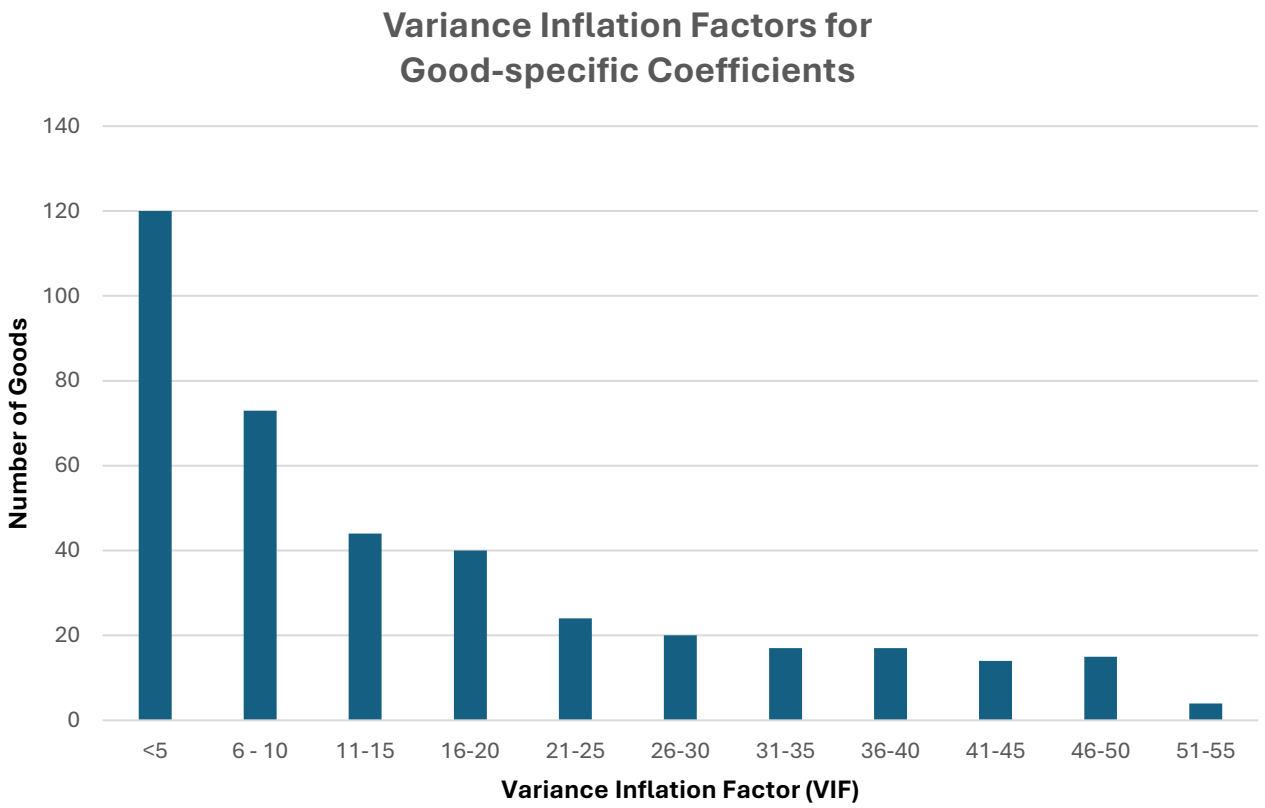
https://online.stat.psu.edu/stat462/node/180/

IDC data

- Granular data on revenues and quantities for smartphones sold in the US
- Based on estimates formed by IDC, a consultancy.
- Only 700 or so goods allows us to use the usual specification (dummy variables)

	IDC
Sector	Smartphones
Data Source	IDC estimates
Market	US
Frequency	quarterly
Time periods	20
Goods (number)	699
Observations (number)	3925
Median obs/good	6

IDC data: actual data
There is a collinearity problem with the fixed effect coefficients…..



- 698 VIFs for goods
- Over 70% of the coefficients have a severe collinearity problem: VIF>10
- Only 38% of the coefficients are significantly different from zero at least at the 10% level

Statistical Significance of Coefficients		
	Goods	
	Number	Percent
<.1	260	37.7%
<.05	205	29.7%
<.025	157	22.8%
<.01	113	16.4%

...but the time dummy coefficients do not appear affected

Time Dummy Coefficients

Time period	VIF	Estimate	Standard Error	P-value
2014Q2	**1.99**	-3.4%	0.8%	<.0001
2014Q3	**2.10**	-14.8%	0.8%	<.0001
2014Q4	**2.56**	-18.8%	0.8%	<.0001
2015Q1	**2.30**	-21.3%	0.9%	<.0001
2015Q2	**2.26**	-24.6%	0.9%	<.0001
2015Q3	**2.59**	-33.4%	0.9%	<.0001
2015Q4	**3.30**	-40.0%	1.0%	<.0001
2016Q1	**2.63**	-45.1%	1.0%	<.0001
2016Q2	**2.67**	-49.7%	1.1%	<.0001
2016Q3	**3.04**	-55.8%	1.1%	<.0001
2016Q4	**4.42**	-60.7%	1.2%	<.0001
2017Q1	**3.05**	-61.3%	1.3%	<.0001
2017Q2	**2.75**	-62.6%	1.3%	<.0001
2017Q3	**3.23**	-70.3%	1.4%	<.0001
2017Q4	**3.52**	-73.9%	1.5%	<.0001
2018Q1	**3.09**	-76.1%	1.6%	<.0001
2018Q2	**2.93**	-77.1%	1.6%	<.0001
2018Q3	**2.47**	-80.1%	1.7%	<.0001
2018Q4	**2.31**	-86.6%	1.8%	<.0001

- VIFs for 19 time periods
- None of the coefficients appear to have a collinearity problem (all VIF<5)
  - Time dummy variables are not correlated with the fixed effects
- Coefficients have P-values>.0001.

IDC data: Experiment

Variance Inflation Factors			
	Observations Per Good		
Time Period	2	≤ 5	Actual Data
2014Q2	1.9	2.0	2.0
2014Q3	14.5	2.1	2.1
2014Q4	28.3	2.7	2.6
2015Q1	14.4	2.5	2.3
2015Q2	19.2	2.6	2.3
2015Q3	64.4	3.9	2.6
2015Q4	125.4	5.8	3.3
2016Q1	37.3	4.6	2.6
2016Q2	87.3	4.7	2.7
2016Q3	114.3	6.0	3.0
2016Q4	241.6	9.5	4.4
2017Q1	21.7	6.1	3.1
2017Q2	27.9	5.0	2.8
2017Q3	138.1	6.6	3.2
2017Q4	211.6	7.6	3.5
2018Q1	37.8	6.3	3.1
2018Q2	27.8	5.8	2.9
2018Q3	32.4	4.4	2.5
2018Q4	22.3	3.1	2.3
VIF>=5 number	18	8	0
% of coefficients	95%	42%	0%

Construct versions of the data that include fewer observations per good.

- Worst case scenario: VIFs for data with only 2 observations per good are substantially high
- Data with 5 or less observations per good is considerably better behaved
- Actual data (median of 6 observations: VIFs do not detect a collinearity problem

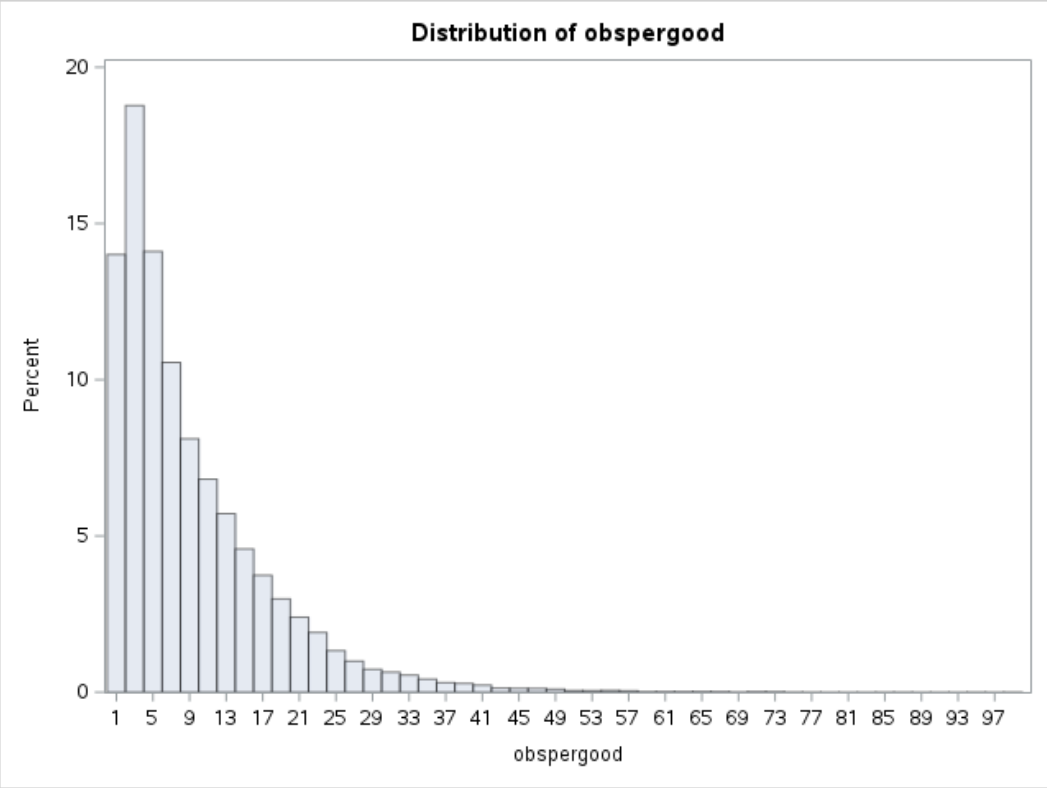
Alternative fixed effects specification for large numbers of goods

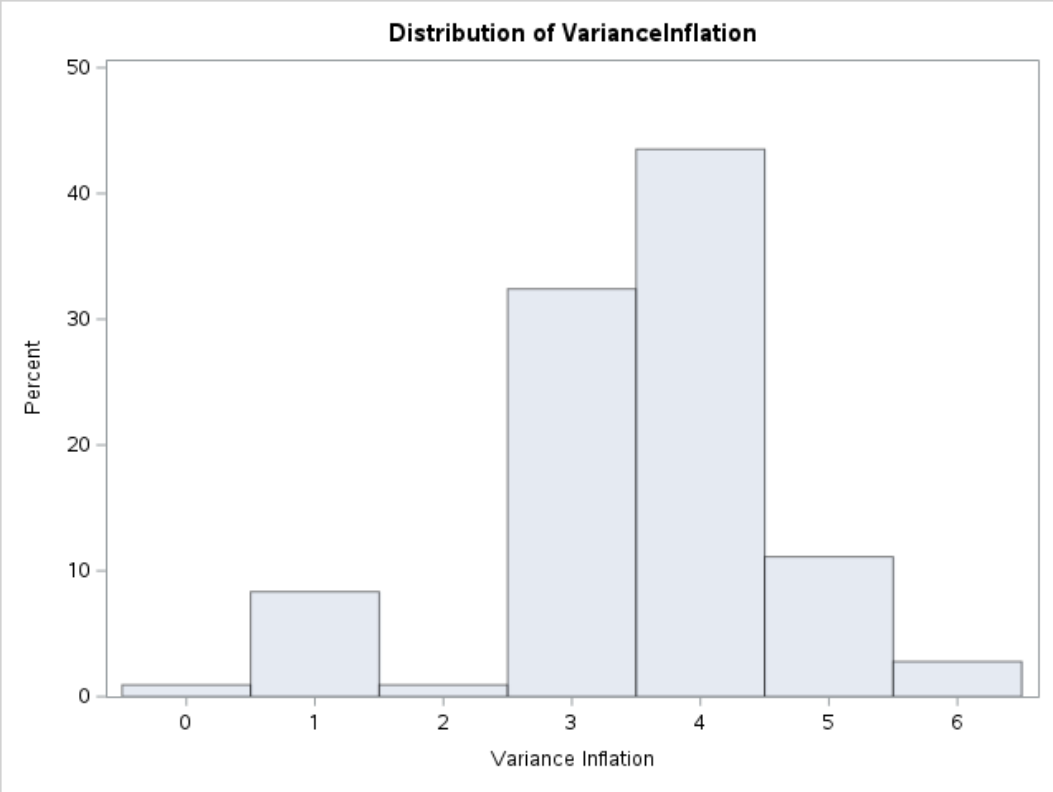
Time-demeaned specification:

- Take means of all variables, which removes the good-specific fixed effects
  - In our case, weighted means
- WLS of the demeaned (logged) price on the (demeaned) time dummy variables
  - The two specifications are equivalent and give the same δ^t's estimates and standard errors
  - This facilitates estimating WTPD coefficients and assessing collinearity issues
  - This specification is preferred if one does not need to estimate the individual γ_i 's.

Time Dummy Coefficients					
Parameter Estimate		Standard Errors		Variance Inflation Factors	
Usual	Demeaned	Usual	Demeaned	Usual	Demeaned
-0.03	-0.03	0.01	0.01	1.99	1.56
-0.15	-0.15	0.01	0.01	2.10	1.85
-0.19	-0.19	0.01	0.01	2.56	2.12
-0.21	-0.21	0.01	0.01	2.30	2.04
-0.25	-0.25	0.01	0.01	2.26	1.99
-0.33	-0.33	0.01	0.01	2.59	2.31
-0.40	-0.40	0.01	0.01	3.30	2.58
-0.45	-0.45	0.01	0.01	2.63	2.30
-0.50	-0.50	0.01	0.01	2.67	2.28
-0.56	-0.56	0.01	0.01	3.04	2.73
-0.61	-0.61	0.01	0.01	4.42	3.38
-0.61	-0.61	0.01	0.01	3.05	2.69
-0.63	-0.63	0.01	0.01	2.75	2.46
-0.70	-0.70	0.01	0.01	3.23	2.89
-0.74	-0.74	0.02	0.01	3.52	2.80
-0.76	-0.76	0.02	0.01	3.09	2.59
-0.77	-0.77	0.02	0.01	2.93	2.52
-0.80	-0.80	0.02	0.02	2.47	2.15
-0.87	-0.87	0.02	0.02	2.31	1.91

Scanner data for desktops: Monthly

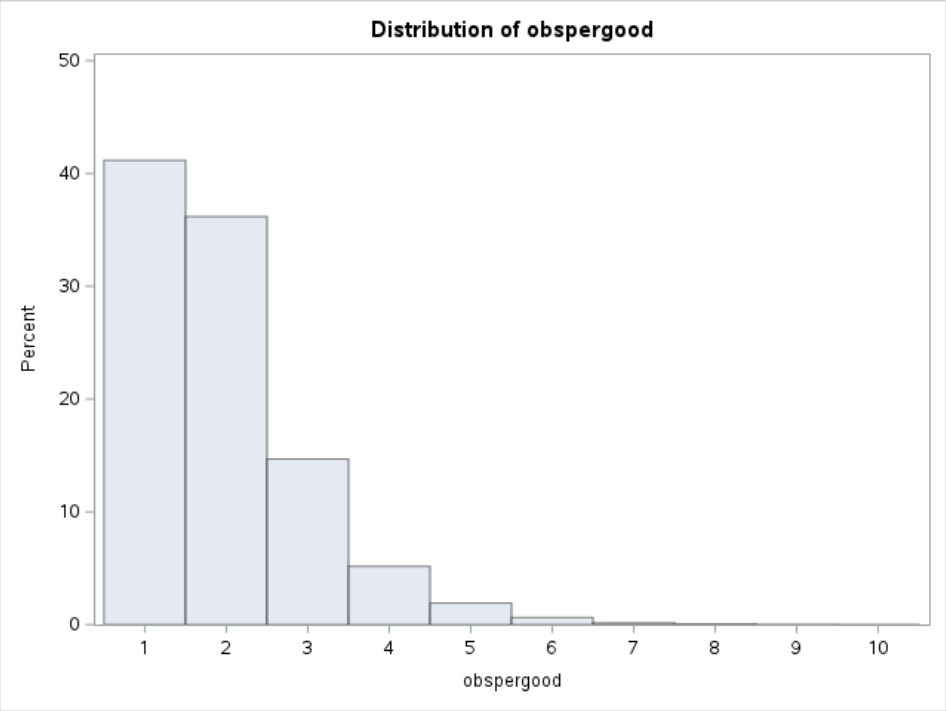




- Number of observations 362K
- Number of goods: 41K
- Median observations per good: 6
- Number of time periods: 120

→ mild collinearity issue

Scanner data for desktops: Annual



Time Dummy Coefficients

Year	Estimate	Standard Error	P-value	VIF
2012	-2.0%	0.1%	<.0001	1.7
2013	-5.8%	0.1%	<.0001	3.4
2014	-7.8%	0.1%	<.0001	6.0
2015	-11.3%	0.2%	<.0001	7.3
2016	-15.2%	0.2%	<.0001	7.2
2017	-18.7%	0.2%	<.0001	9.4
2018	-19.7%	0.2%	<.0001	8.6
2019	-22.3%	0.2%	<.0001	9.6
2020	-19.6%	0.2%	<.0001	6.4

- Nobs 79K
- Number of goods: 41K
- Median observations per good: 2
- Number of time periods: 10

→ bigger collinearity issue

Conclusions

- TPD time dummy coefficients can show collinearity issues, but the problem is not overwhelming in our data
  - Need to apply diagnostics to other data sets to assess prevalence and numerical importance of the issue.

- The degree of the problem seems to depend on the number of periods a good is sold. We see that in
  - experiments with the IDC data, and
  - low vs high frequency versions of Circana data.

- Practical lessons for price deflation:
  - TPD price index seems worth pursuing further
    - No statistical bias (relative to TDH)
    - Collinearity issues may not be as severe as one would think
  - Demeaned version of the model is a promising strategy
  - Aggregating to lower frequency data (e.g., annual) could increase collinearity problem

Thank you

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