Econometrics Spring School 2016
Econometric Modelling

Jurgen A Doornik, David F. Hendry, and Felix Pretis

George-Washington University

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Lecture 10: Empirical Modelling In Action

Practice of empirical modelling

Multiple concepts introduced around **Empirical Model Discovery**:

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- Starting point: theory model

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- Automatic Testing for Non-linearity

How to apply them all in practice?

- Crucial: conduct everything jointly rather than treating 'symptoms' individually

In-Practice: US Food Demand

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- Automatic Testing for Non-linearity (E)

In-Practice: US Food Demand

Apply concepts to **US Food Demand** (Hendry and Mizon, 2011)

- Starting point: theory model – food demand (A)
- Automatically extend model – dynamics (B)
- Embed theory: general-to-specific selection – Autometrics (C)
- Detection of Outliers and Structural Breaks – IIS/SIS (D)
- Automatic Testing for Non-linearity – Principal Comp. Test (E)

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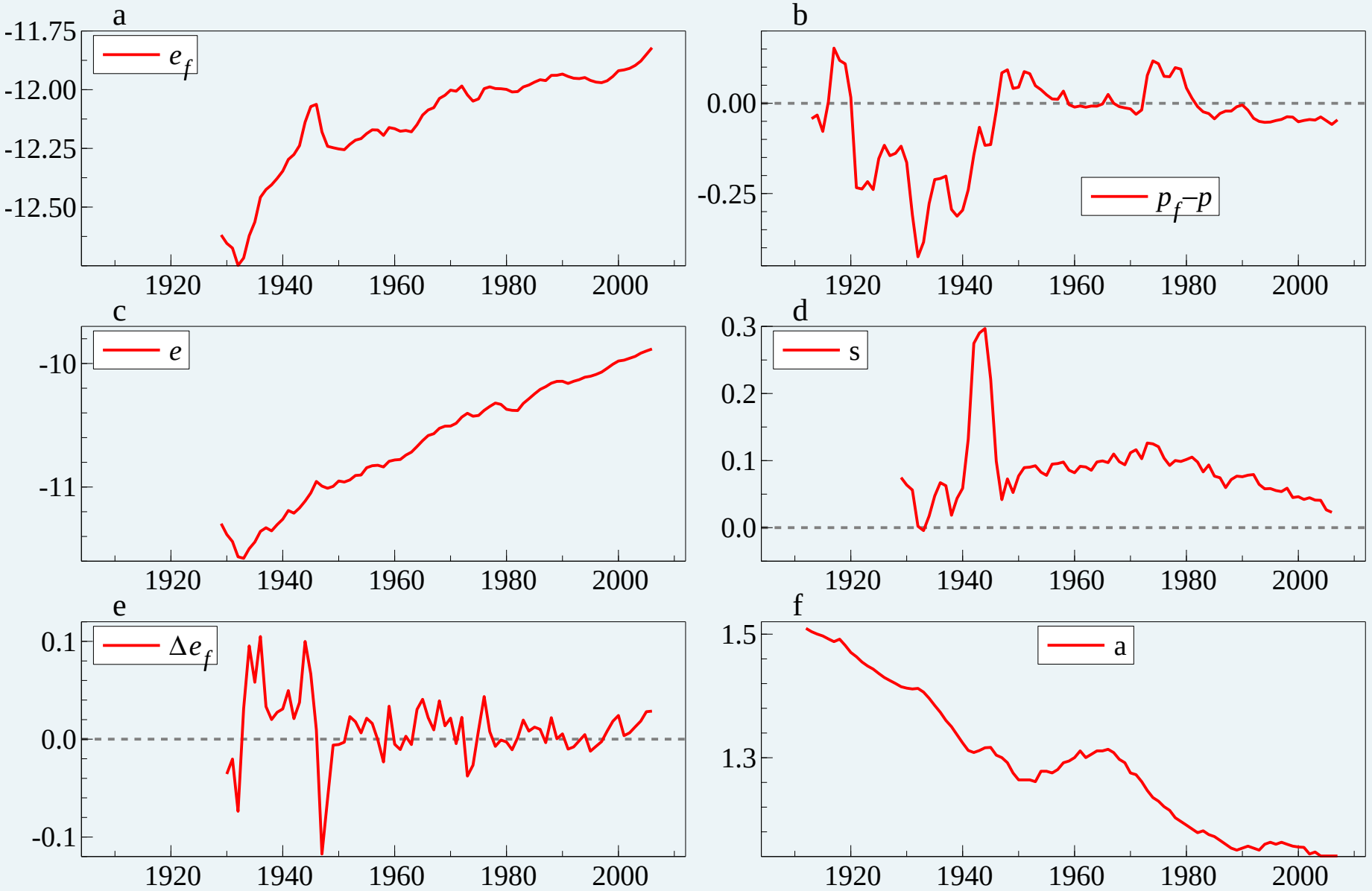
  - n is total population of the USA–
    should be irrelevant as per capita data.

The Data


a
e_f
-11.75
-12.00
-12.25
-12.50
1920
1940
1960
1980
2000
b
$p_f - p$
0.00
-0.25
c
e
-10
-11
d
s
0.3
0.2
0.1
0.0
e
Δe_f
0.1
0.0
-0.1
f
a
1.5
1.3

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- Conventional theory expects:

$$\frac{\partial e_f}{\partial e} > 0, \quad \frac{\partial e_f}{\partial \left(p_f - p\right)} < 0, \quad \frac{\partial e_f}{\partial s} > 0, \quad \frac{\partial e_f}{\partial a} < 0, \quad \frac{\partial e_f}{\partial n} = 0 \tag{2}$$

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- a (panel f) has fallen considerably, partly reflecting changes in social mores.

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- We model e_f conditional on $e, s,$ and $p_f - p$: which Hendry (2009) showed were weakly exogenous in food-demand equation.
- Illustrates that even if an economic theory is basically correct, it need not be coherent with the data.
  Estimated **static** model is seriously mis-specified and has wrong coefficient signs: either outcome could lead to the false rejection of the theory.

Empirical Model Discovery:

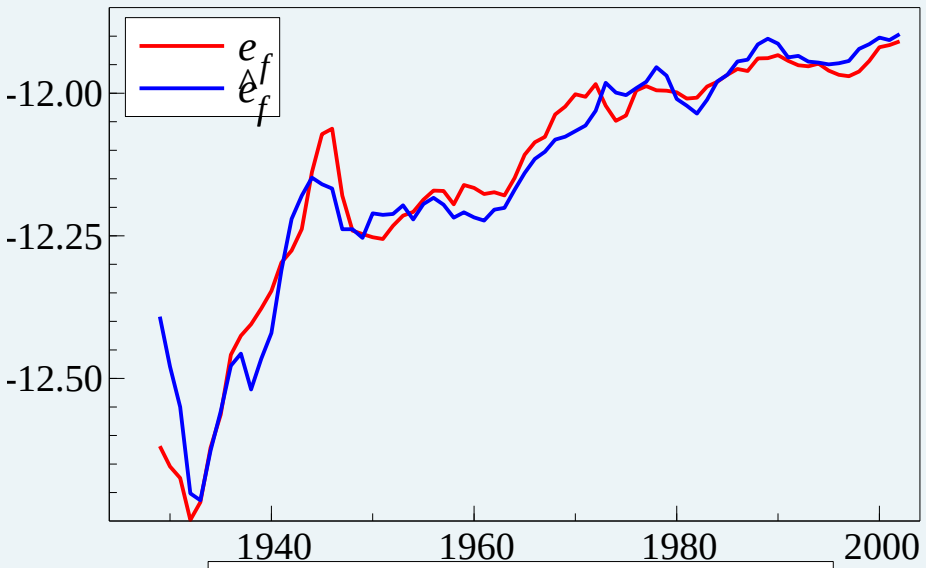
- (A) Estimate static theory model
  - e_f is constant price, per capita, expenditure on food
  - e is constant price, per capita, total expenditure
  - p is deflator of total expenditure
  - y is constant price, per capita, income
  - $p_f - p$ is real price of food
  - $s = (y - e)$ is an approximation to the savings ratio
  - a is average family size–demographic effects
  - n is total population of the USA–
    should be irrelevant as per capita data.
  - Sample: 1929–2002

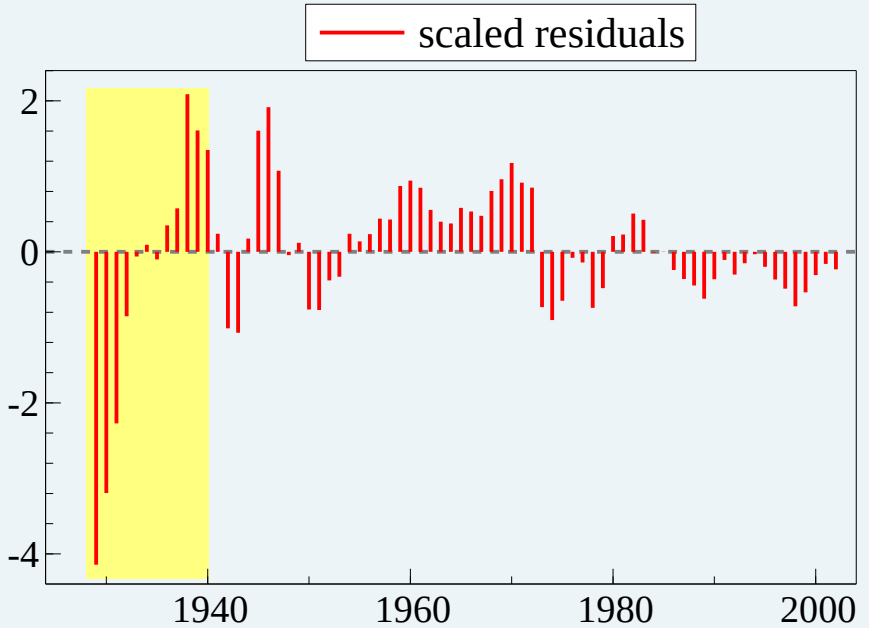
The static theory model estimates are:

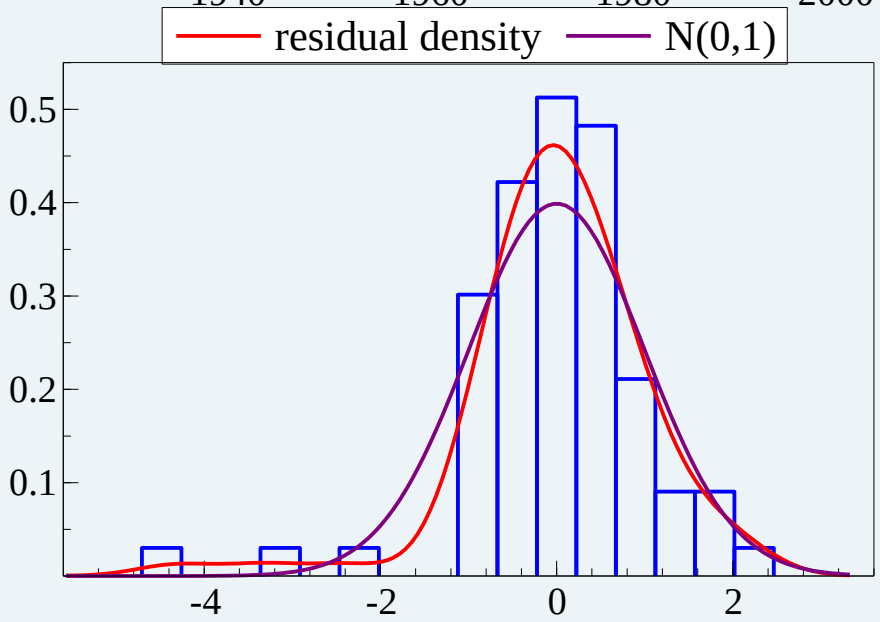
$$\begin{aligned} e_{f,t} &= \underset{(4.02)}{5.30} + \underset{(0.14)}{0.77}\, e_t + \underset{(0.08)}{0.11}\, (p_f - p)_t + \underset{(0.14)}{0.72}\, s_t - \underset{(0.23)}{0.36}\, a_t - \underset{(0.22)}{0.73}\, n_t \\ R^2 &= 0.94 \;\; \chi^2_{nd}(2) = 19.5^{**} \;\; F_{arch}(1,72) = 216.8^{**} \;\; F_{ar}(2,66) = 44.3^{**} \\ \widehat{\sigma} &= 0.055 \;\; F_{reset}(2,66) = 18.1^{**} \;\; F_{het}(10,63) = 23.2^{**} \end{aligned}$$

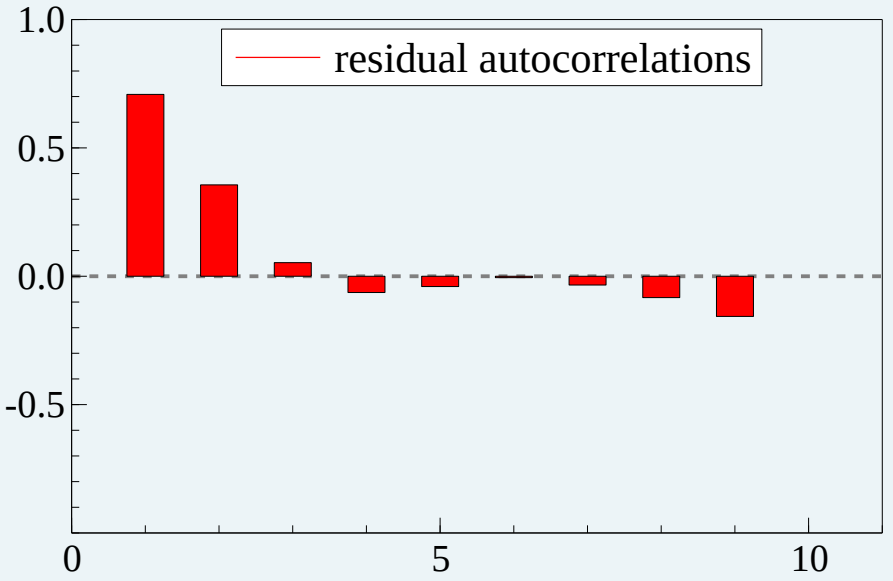
- The static economic-theory model has a very poor fit, and does not adequately capture behaviour of observed data.
- The price elasticity $(p_f - p)_t$ has the 'wrong sign', contradicting (2), but is insignificant.
- Although it is theoretically irrelevant, population n_t is significant.
- Finally, every mis-specification test strongly rejects.
  Next Figure shows the estimated model fails to describe the 1930s.

Static ‘theory’ equation









(A) + (D): Static Model with IIS

Poor performance and different behaviour of the pre and post WWII: IIS is next introduced into the specification.

Empirical Model Discovery:

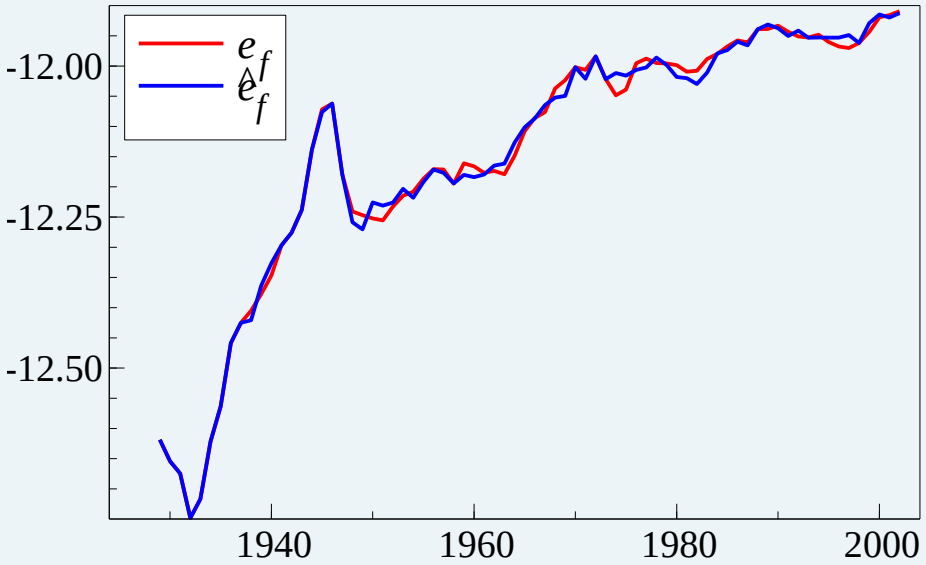
- (A) Estimate static theory model (forced: `U - fixed`)
- (D) Checking for outlying observations (IIS) at $p_\alpha = 0.01$

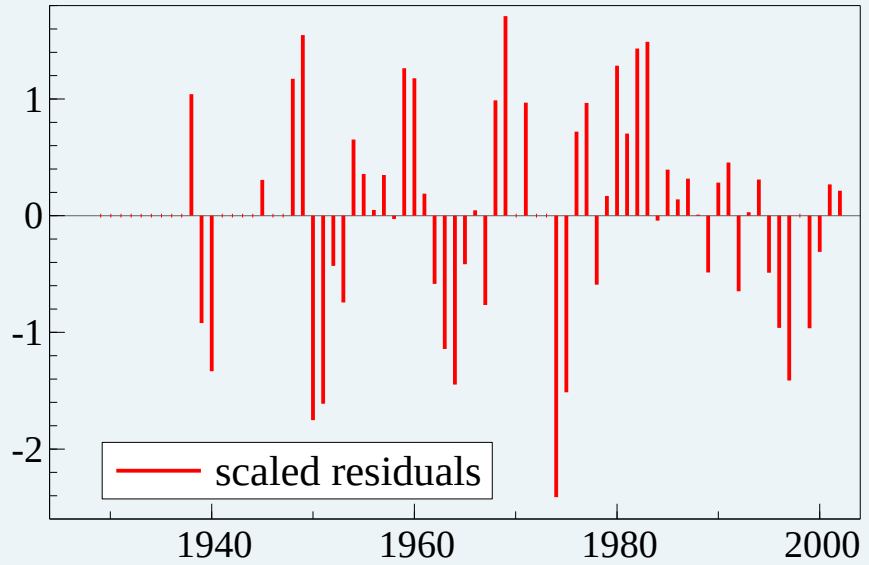
Poor performance and different behaviour of the pre- and post-WWII: IIS. **Resulting model** is:

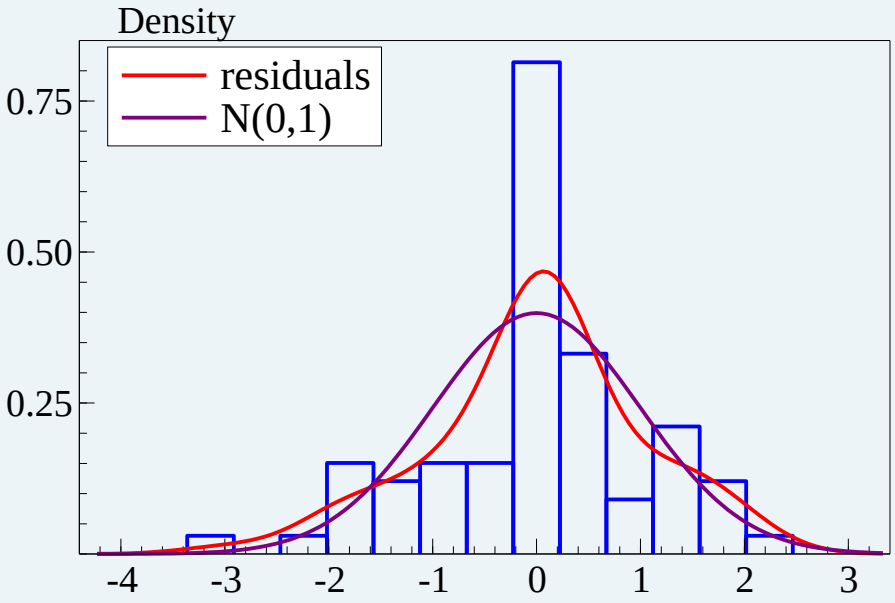
$$
\begin{aligned}
e_{f,t} = {} & \underset{(0.06)}{0.64}\, e_t - \underset{(0.03)}{0.15}\, (p_f - p)_t + \underset{(0.1)}{1.0}\, s_t - \underset{(0.08)}{0.01}\, a_t - \underset{(0.10)}{0.47}\, n_t \\
& + \underset{(1.8)}{0.24} - \underset{(0.02)}{0.30}\, I_{29} - \underset{(0.02)}{0.27}\, I_{30} - \underset{(0.02)}{0.26}\, I_{31} - \underset{(0.02)}{0.21}\, I_{32} \\
& - \underset{(0.02)}{0.16}\, I_{33} - \underset{(0.02)}{0.12}\, I_{34} - \underset{(0.02)}{0.11}\, I_{35} - \underset{(0.02)}{0.08}\, I_{36} - \underset{(0.02)}{0.06}\, I_{37} \\
& - \underset{(0.02)}{0.08}\, I_{41} - \underset{(0.02)}{0.17}\, I_{42} - \underset{(0.02)}{0.16}\, I_{43} - \underset{(0.02)}{0.10}\, I_{44} + \underset{(0.02)}{0.10}\, I_{46} \\
& + \underset{(0.02)}{0.09}\, I_{47} + \underset{(0.02)}{0.03}\, I_{70} + \underset{(0.02)}{0.03}\, I_{72} - \underset{(0.02)}{0.034}\, I_{73} - \underset{(0.02)}{0.03}\, I_{98}
\end{aligned}
$$

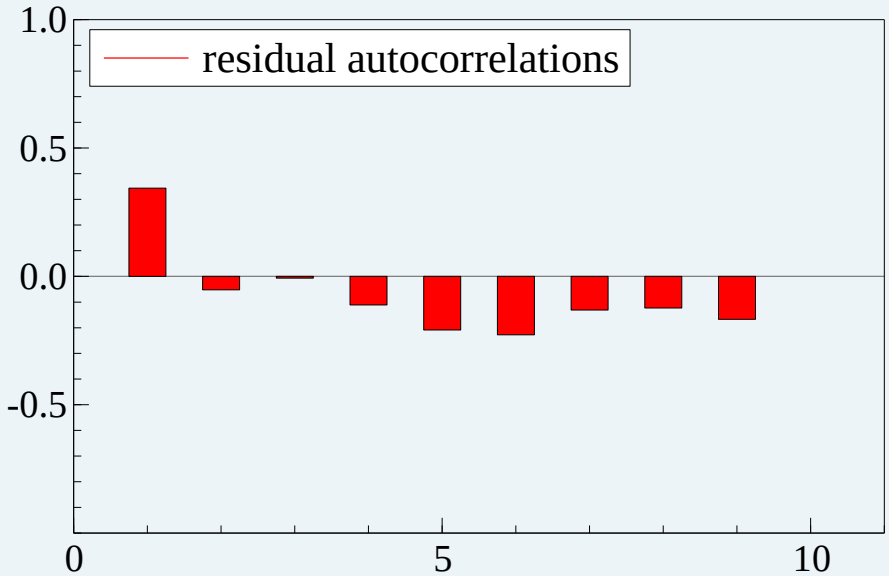
$$
\begin{aligned}
R^2 = {} & 0.997 \;\; \widehat{\sigma} = 0.015 \;\; F_{ar}(2,47) = 4.9 \;\; \chi^2_{nd}(2) = 2.3 \\
& F_{arch}(1,72) = 6.7^* \;\; F_{reset}(2,47) = 3.1 \;\; F_{het}(10,44) = 2.3
\end{aligned}
$$

Static 'theory' equation with IIS









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- Equally, cannot conclude that the theory is wrong *per se* because reject null of no impulse indicators, only that in its static form it is wrong.
- In fact features of the data 'outside' of the theory which induce that failure (mainly location shifts from policy interventions and wars), and the final model we obtain satisfies most of the theory for most of the sample.

(A) + (B): Dynamic Models

Static model (with or without Impulses) likely misses dynamics.

Empirical Model Discovery:

- (A) Estimate static theory model
- (B) Automatic model extensions: dynamics, add two-lags of each variable

$$
\begin{aligned}
e_{f,t} = {} & \underset{(0.08)}{0.71}\, e_t - \underset{(0.06)}{0.20}\, (p_f - p)_t + \underset{(0.08)}{0.26}\, s_t + \underset{(0.39)}{0.05}\, a_t \\
& + \underset{(1.5)}{0.13}\, n_t + \underset{(0.14)}{0.98}\, e_{f,t-1} - \underset{(0.12)}{0.14}\, e_{f,t-2} - \underset{(0.13)}{0.73}\, e_{t-1} \\
& + \underset{(0.12)}{0.01}\, e_{t-2} + \underset{(0.09)}{0.25}\, (p_f - p)_{t-1} - \underset{(0.06)}{0.04}\, (p_f - p)_{t-2} \\
& + \underset{(0.13)}{0.01}\, s_{t-1} - \underset{(0.09)}{0.04}\, s_{t-2} - \underset{(0.38)}{0.10}\, a_{t-1} - \underset{(2.72)}{1.45}\, n_{t-1} \\
& + \underset{(1.41)}{1.41}\, n_{t-2} - \underset{(1.80)}{3.10} \qquad (3)
\end{aligned}
$$

$$
\begin{aligned}
R^2 &= 0.996 \;\; \widehat{\sigma} = 0.015 \;\; F_{ar}(2,53) = 0.56 \;\; \chi^2_{nd}(2) = 0.14 \\
F_{arch}(1,70) &= 2.60 \;\; F_{reset}(2,53) = 1.79 \;\; F_{het}(32,39) = 3.78^{**}
\end{aligned}
$$

Improved fit, but heterossk. and no cointegration $t_{ur} = -2.59$ (Banerjee, Dolado, and Mestre, 1998); pseudo long-run elasticities of $(p_f - p)$ and e have wrong signs: **not just dynamics.**

Empirical Model Discovery:

- (A) Estimate static theory model
- (B) Automatic model extensions: dynamics, two lags.
- (C) Theory-embedding in general-to-specific selection (`U - fixed`)
- (D) Checking for outlying observations (IIS), $p_\alpha = 0.01$

- Next use general-to-specific selection (*Autometrics*) with theory variables retained, selecting over dynamics and IIS:
  - vast improvement in coherence of theory and evidence
  - anticipated signs on long-run elasticities
  - cointegration is clearly indicated
  - main impulses are for a food program in Depression, WWII, the Korean War, with smaller impacts in the early 1970s.

$$
\begin{aligned}
e_f = & \underset{(0.035)}{0.49}\ e_{f,t-1} - \underset{(0.055)}{0.21}\ e_{t-1} + \underset{(0.019)}{0.14}\ (p_f - p)_{t-2} \\
& + \underset{(0.047)}{0.27}\ s_{t-1} - \underset{(0.015)}{0.15}\ I_{t_3 1} - \underset{(0.016)}{0.16}\ I_{32} \\
& - \underset{(0.011)}{0.062}\ I_{33} - \underset{(0.0097)}{0.034}\ I_{43} - \underset{(0.0087)}{0.028}\ I_{t_5 0} \\
& + \underset{(0.0082)}{0.031}\ I_{70} - \underset{(0.0083)}{0.025}\ I_{73} + \underset{(0.93)}{2.1} \\
& + \underset{(0.044)}{0.61}\ e_t - \underset{(0.023)}{0.2}\ (p_f - p)_t + \underset{(0.038)}{0.21}\ s_t \\
& + \underset{(0.04)}{0.072}\ \mathsf{a}_t - \underset{(0.06)}{0.34}\ \mathsf{n}_t
\end{aligned}
$$

$$
\mathsf{F}_{\mathsf{ar}}(2,53) = 0.16 \quad \chi^2_{\mathsf{nd}}(2) = 0.07 \quad \mathsf{F}_{\mathsf{arch}}(1,70) = 0.01
$$

$$
\mathsf{F}_{\mathsf{reset}}(2,53) = 1.25 \quad \mathsf{F}_{\mathsf{het}}(18,46) = 0.95
$$

Empirical Model Discovery – without 'forcing' theory:

- (A) Estimate static theory model
- (B) Automatic model extensions: dynamics, two-lags
- (C) Theory-embedding in general-to-specific selection (selected over, not 'forced')
- (D) Checking for outlying observations (IIS), $p_\alpha = 0.01$
- (E) Automatic testing for non-linearity

- **Not treating 'symptoms' individually but all jointly!**
- Selecting over all variables in a GUM with 2 lags and IIS at $p_\alpha = 0.01$ produces almost identical results–only insignificant variables eliminated:

$$\begin{aligned} e_{f,t} = & \underset{(0.04)}{0.59}\ e_t - \underset{(0.03)}{0.32}\ (p_f - p)_t + \underset{(0.04)}{0.23}\ s_t - \underset{(0.02)}{0.16}\ n_t + \underset{(0.05)}{0.77}\ e_{f,t-1} \\ & - \underset{(0.04)}{0.13}\ e_{f,t-2} - \underset{(0.05)}{0.36}\ e_{t-1} + \underset{(0.03)}{0.27}\ (p_f - p)_{t-1} + \underset{(0.05)}{0.17}\ s_{t-1} \\ & - \underset{(0.01)}{0.11}\ I_{31} - \underset{(0.01)}{0.11}\ I_{32} + \underset{(0.01)}{0.03}\ I_{34} - \underset{(0.01)}{0.03}\ I_{43} + \underset{(0.01)}{0.03}\ I_{70} \end{aligned}$$

$$(\mathrm{R}^*)^2 = 0.999\ \ \widehat{\sigma} = 0.0085\ \ \mathrm{F}_{\mathsf{ar}}(2,56) = 0.69\ \ \chi^2_{\mathsf{nd}}(2) = 1.69$$

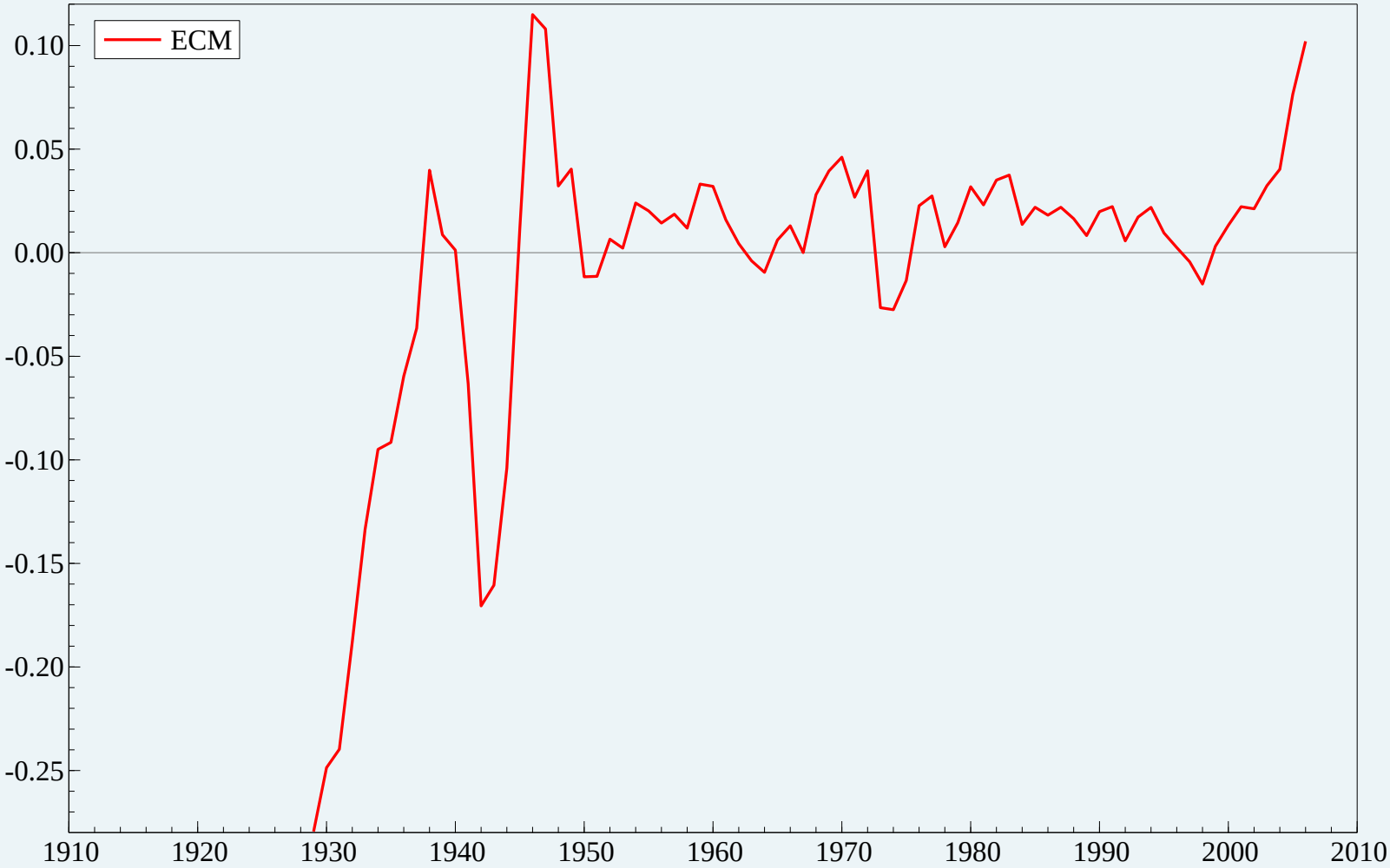
$$\mathrm{F}_{\mathsf{arch}}(1,70) = 0.19\ \ \mathrm{F}_{\mathsf{reset}}(2,56) = 1.16\ \ \mathrm{F}_{\mathsf{het}}(18,48) = 1.02$$

Solved cointegrating relation with dummies excluded:

$$\begin{aligned} ECM &= e_f - \underset{(0.01)}{0.63}\ e + \underset{(0.04)}{0.13}\ (p_f - p) - \underset{(0.08)}{1.12}\ s + \underset{(0.01)}{0.45}\ n \\ \mathrm{t}_{ur} &= -12.1^{**} \end{aligned}$$

Not just an issue of model selection.

Equilibrium Relationship



Empirical Model Discovery – without 'forcing' theory:

- (A) Estimate static theory model
- (B) Automatic model extensions: dynamics
- (C) Theory-embedding in general-to-specific selection (selected over, not 'forced')
- (D) Checking for outlying observations (IIS)
- **(E) Automatic testing for non-linearity**

Index-test for non-linearity:

- $\chi^2(27) = 31.66\ [p = 0.24]$
- or in F-form $F(27, 31) = 0.90\ [p = 0.61]$

$\rightarrow$ **linearity not rejected.**

Write previous model in equilibrium correction form:

- Store ECM Term (using `Algebra`)
- Create $\Delta e_{f,t}, \Delta e_t, \ldots$

$$\begin{aligned}\Delta e_{f,t} = & \underset{(0.06)}{0.14}\ \Delta e_{f,t-1} + \underset{(0.06)}{0.78}\ \Delta e_t - \underset{(0.046)}{0.2}\ \Delta(p_f - p)_t \\ & - \underset{(0.16)}{0.63}\ \Delta n_t + \underset{(0.059)}{0.29}\ \Delta s_t - \underset{(0.027)}{0.2}\ \mathsf{ECM}_{t-1}\end{aligned}$$

$$\mathsf{F_{ar}}(2,64) = 0.35 \quad \chi^2_{\mathsf{nd}}(2) = 3.72 \quad \mathsf{F_{arch}}(1,70) = 3.48$$
$$\mathsf{F_{reset}}(2,64) = 5.97^{**} \quad \mathsf{F_{het}}(12,59) = 7.44^{**}$$

...without IIS fails mis-specification tests.

IIS (at $p_\alpha = 0.01$) and Equilibrium Correction – final model:

$$\begin{aligned}\Delta e_f = & \underset{(0.035)}{0.13}\ \Delta e_{f,t-1} - \underset{(0.012)}{0.11}\ I_{31} - \underset{(0.012)}{0.11}\ I_{32} \\ & + \underset{(0.0096)}{0.028}\ I_{34} - \underset{(0.0096)}{0.027}\ I_{43} + \underset{(0.0085)}{0.031}\ I_{70} \\ & + \underset{(0.04)}{0.59}\ \Delta e_t - \underset{(0.031)}{0.32}\ \Delta(p_f - p)_t - \underset{(0.1)}{0.19}\ \Delta n_t \\ & + \underset{(0.035)}{0.23}\ \Delta s_t - \underset{(0.023)}{0.36}\ \mathsf{ECM}_{t-1}\end{aligned}$$

$$\mathsf{F}_{\mathsf{ar}}(2,59) = 0.68 \quad \chi^2_{\mathsf{nd}}(2) = 1.78 \quad \mathsf{F}_{\mathsf{arch}}(1,70) = 0.27$$
$$\mathsf{F}_{\mathsf{reset}}(2,59) = 0.23 \quad \mathsf{F}_{\mathsf{het}}(12,54) = 1.01$$

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Stability Analysis

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- Set sample up to 1932 (T=22), forecast for 50 periods.

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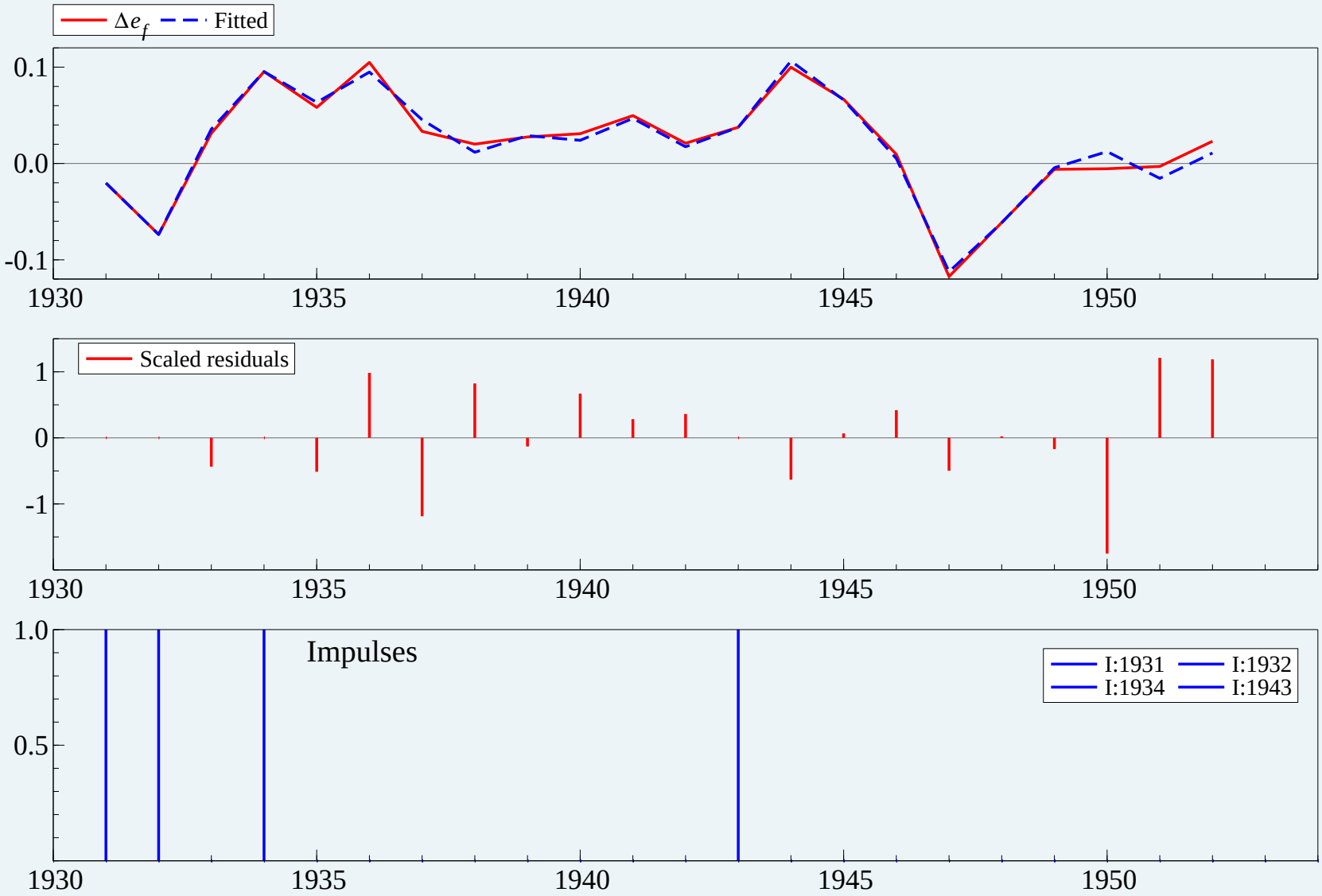
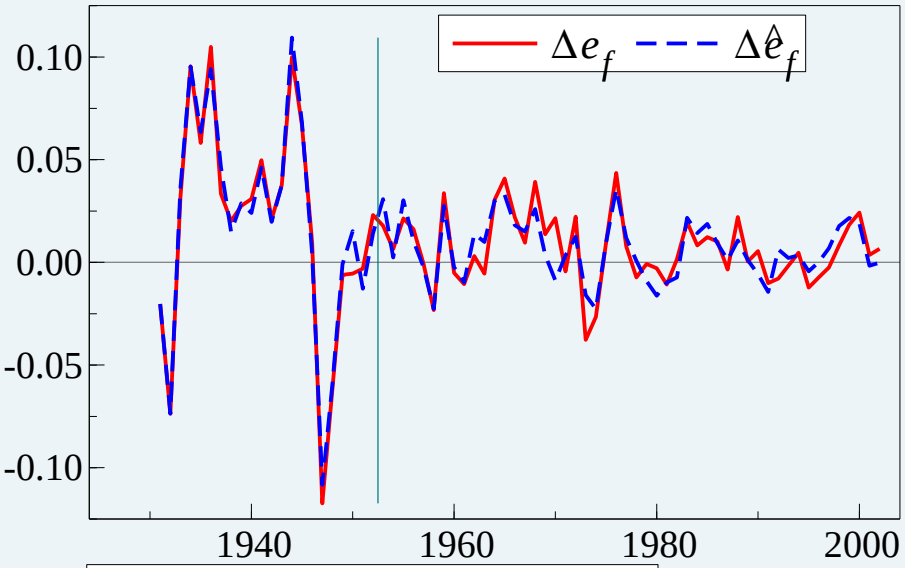
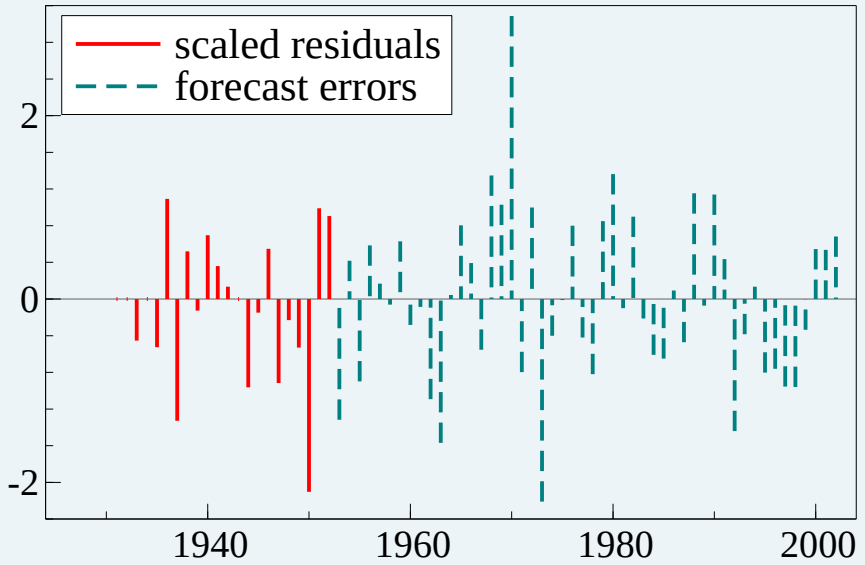
- Set sample up to 1932 (T=22), forecast for 50 periods.
- Note: estimates model over 'problematic' inter-war period.

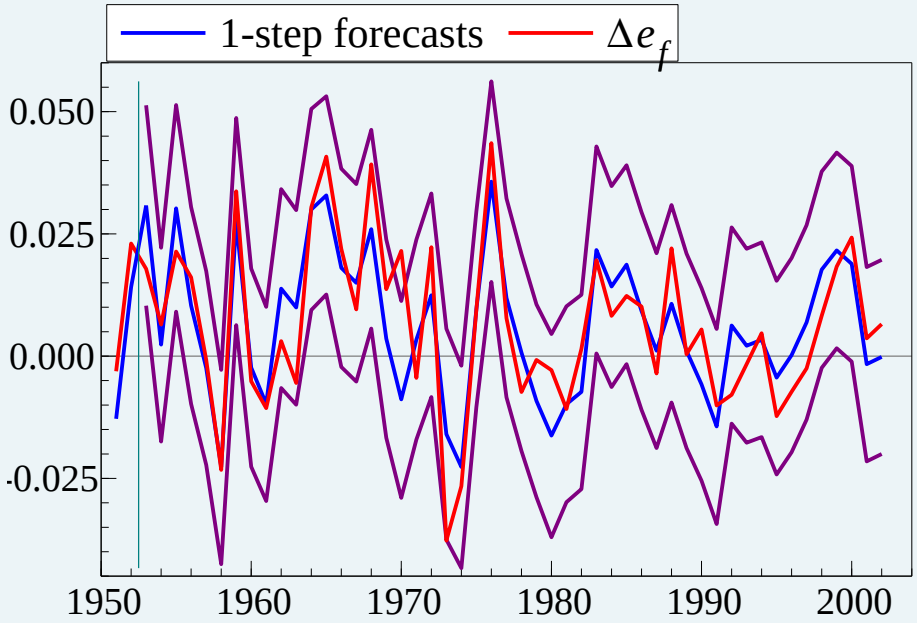
In-sample 1931-1952

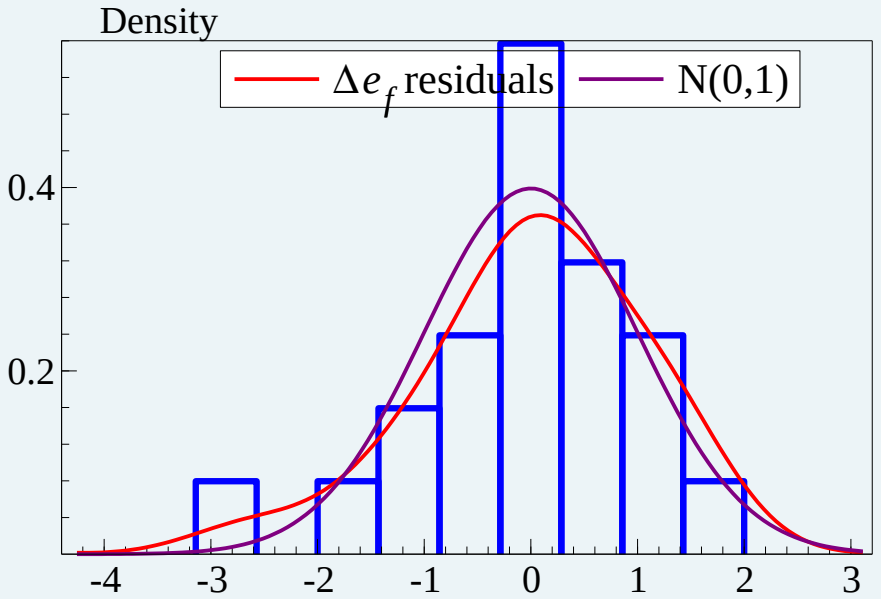


Cond. ‘forecasts’ over 1953–2002









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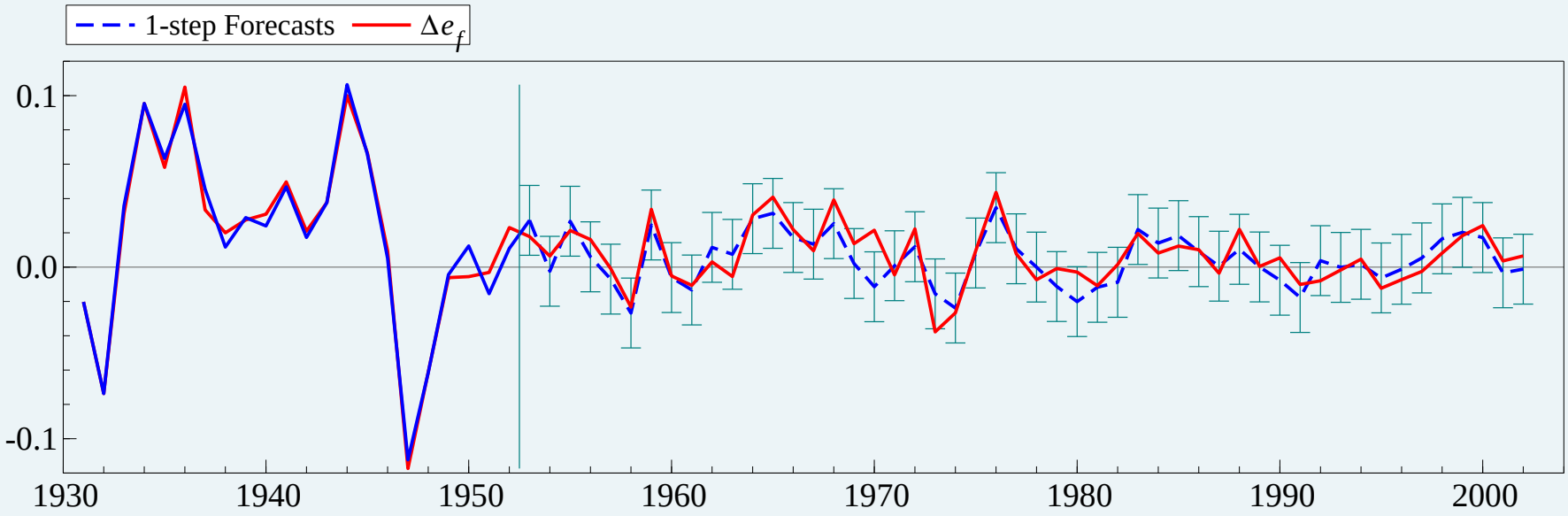
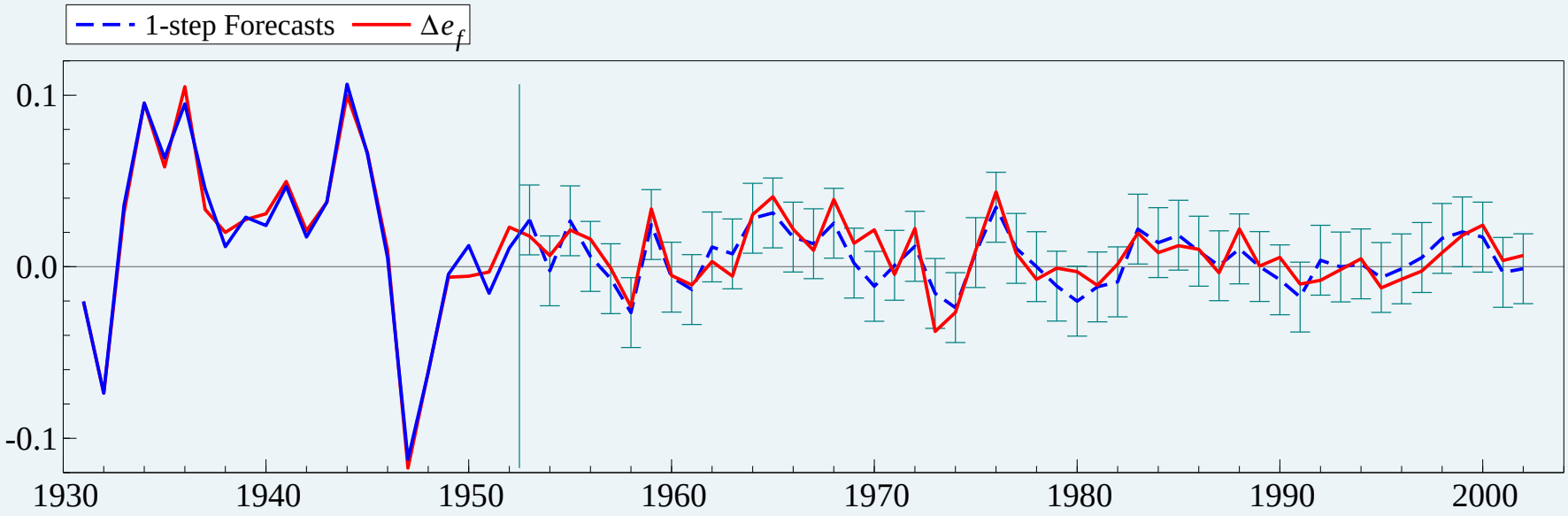


- Performs well–$F_{Chow}(50, 11) = 0.59$.
- **Particularly impressive as that most other investigators of these data omitted the inter-war period as discrepant.**
- Large data variation of inter-war period is invaluable in improving precision of parameter estimates.

Extend the 'forecasts'...



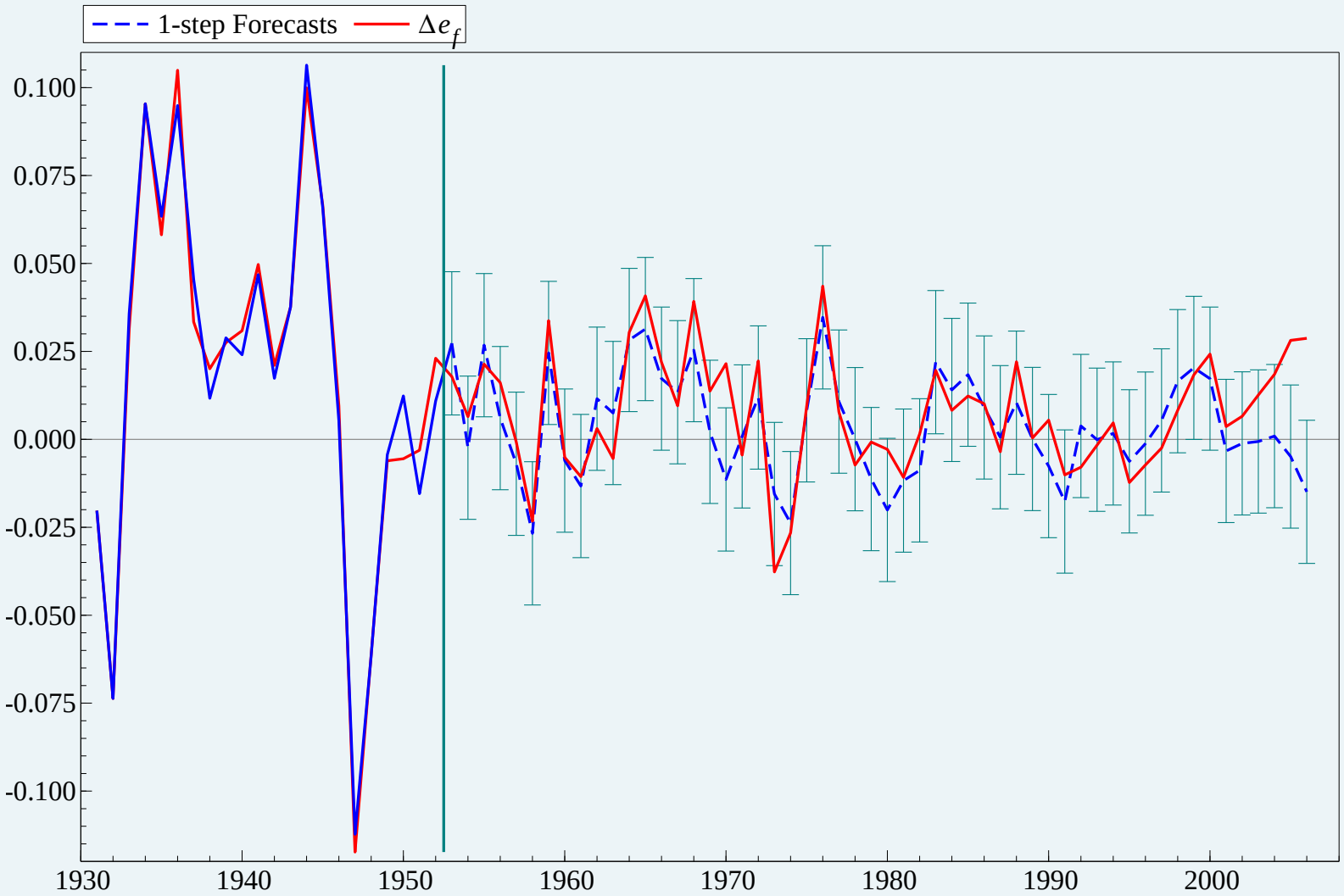
So far:

- well-specified model
- stable model – 'forecasts' well from 1952-2002

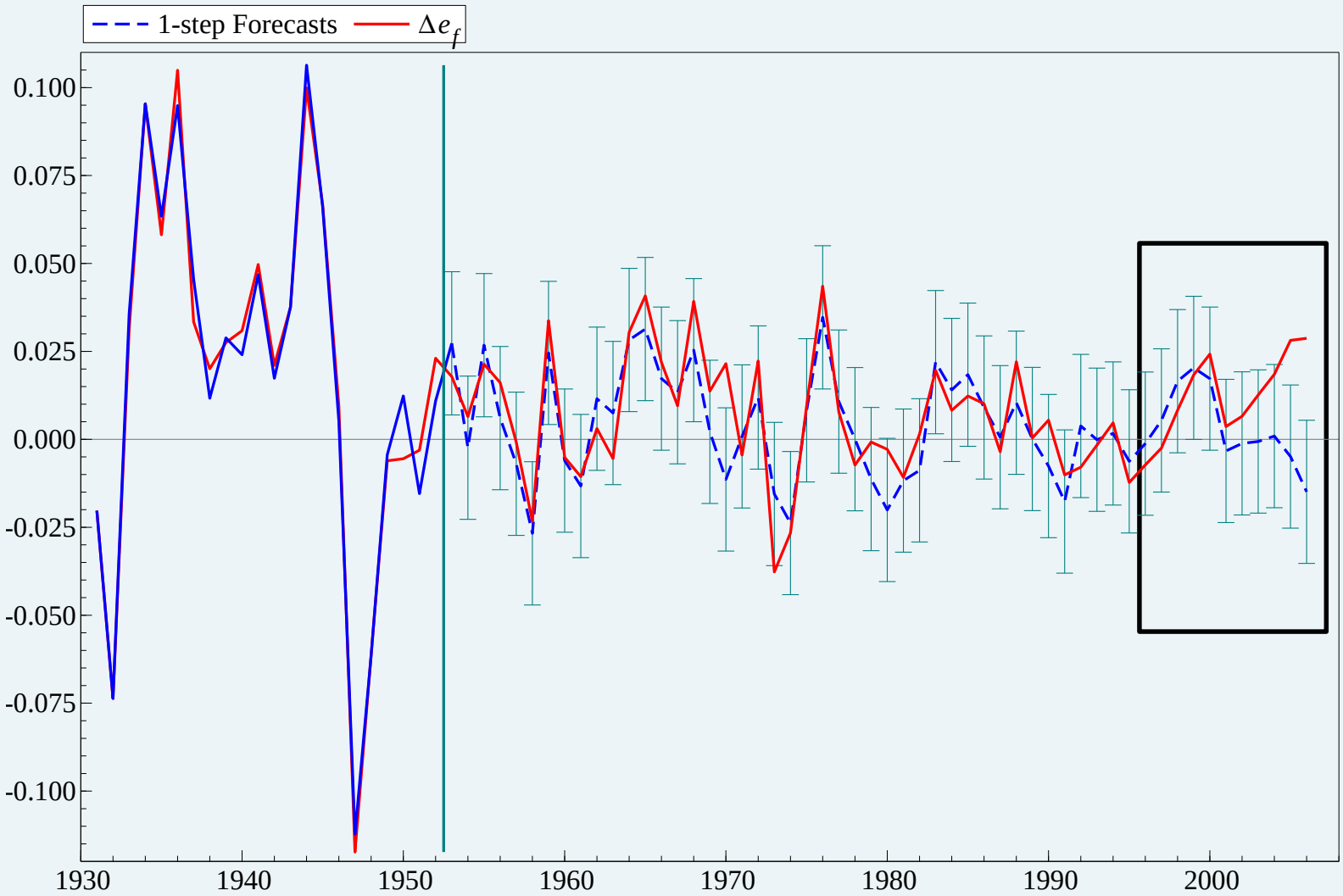
Let's expand the 'forecasts' from 2002 until 2006...

- Sample up to 1952, forecast 54 periods.

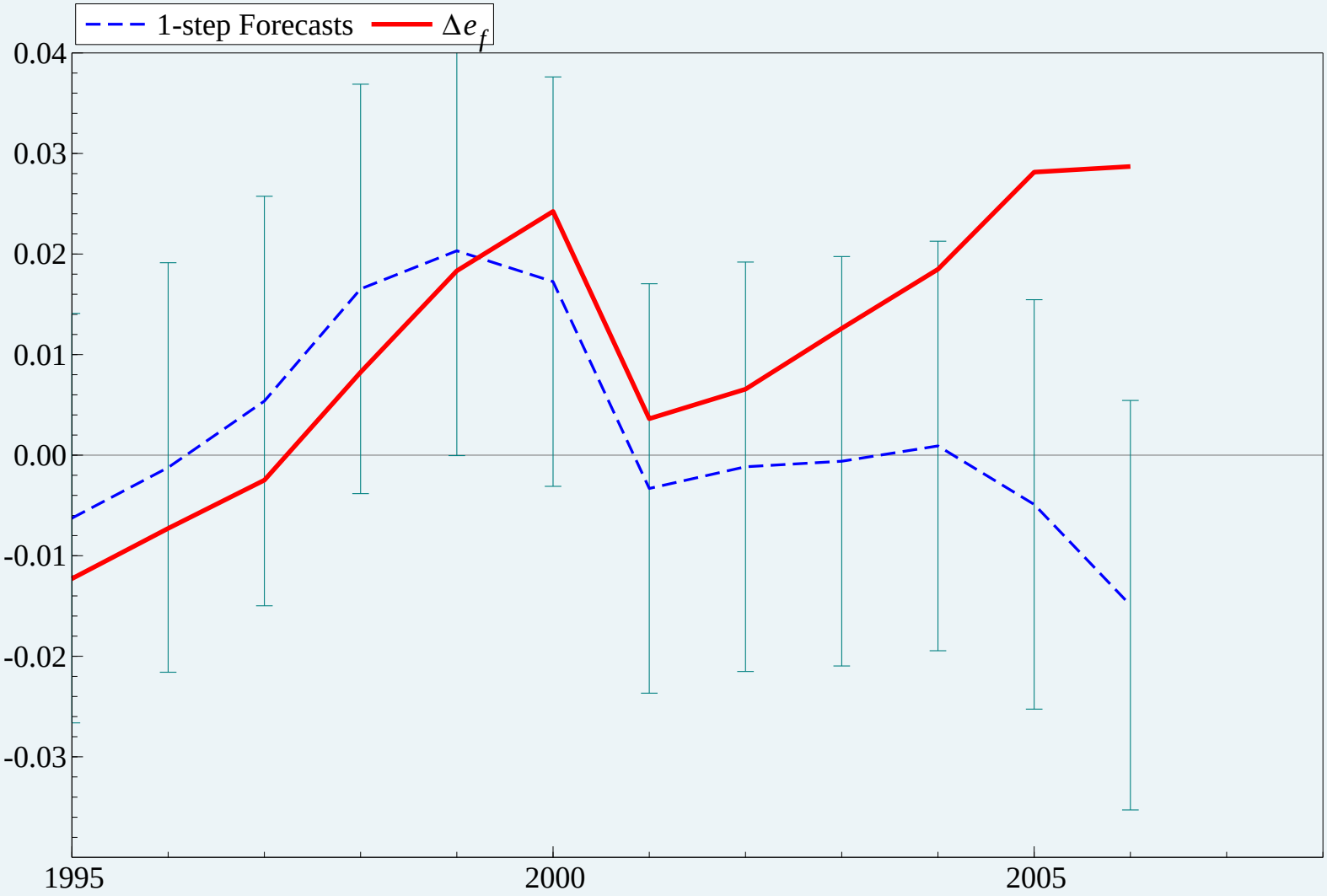
Cond. ‘forecasts’ up to 2006

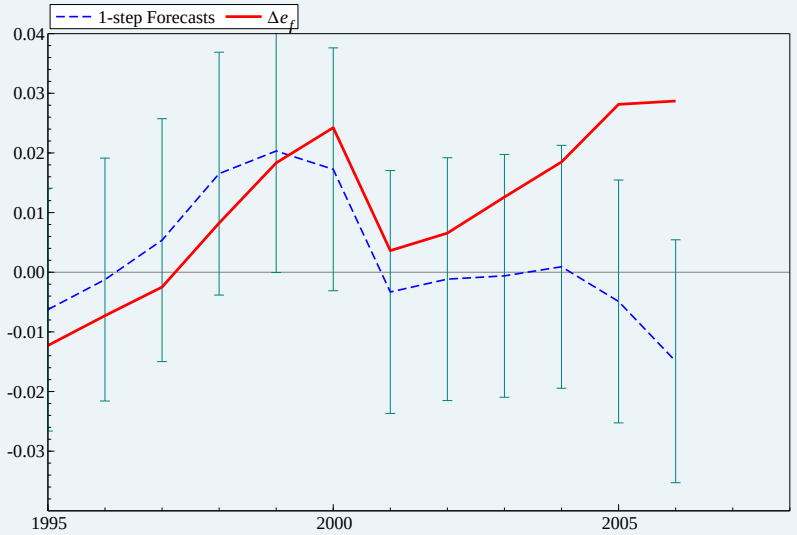


Cond. ‘forecasts’ up to 2006



‘Forecasts’ up to 2006





...forecast failure if expand from 2002 to 2006.

The world is ever changing...

- 'good' models can break down any time
- Could switch to robust forecasting methods
- robust to unexplained locations shifts (but these methods will have to be the focus of another time...)

US Food Demand Example to illustrate principles – crucial: **treat everything jointly.**

- Define a starting model: general unrestricted model (GUM)
  - Designed to be congruent (diagnostic testing) and relevant,
  - Tests of reductions with approximately correct distribution,
  - Reduction can maintain congruence (or lack thereof),
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Model selection is an iterative search procedure, need to follow several paths:

- multiple path search, or
- tree search.

Overall Conclusions

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All the ingredients for empirical model discovery jointly with theory evaluation are in place.

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