Multifactor Productivity
Measurement and Forecasting in the *LIFT* Model

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What is Multifactor Productivity (MFP)?

- **MFP** = output per unit of inputs
  - Real value added / (K, L)
  - Gross output / (KLEMS).
- **The Residual**: changes in output not explained by the change in combined inputs.
- **Many factors** are involved:
  - R&D
  - New technologies
  - Economies of scale
  - Managerial skill
  - Changes in the organization of production.

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MFP: General Themes

- **Productivity**– Classical Economists: machinery can increase the productivity of labor.

- **Statistics** – BLS: early labor productivity measures. BEA and BLS: now jointly developing production accounts

- **Modeling** – What can we gain by incorporating MFP into an IO modeling framework?

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MFP in *LIFT* : Why Now?

+ **New version of LIFT**: based on 2002 benchmark IO and time series of annual IO tables (1998-2010).

+ **Consistent Industry Classification**: industry output, employment, investment, capital stock and value added.

+ The **BEA KLEMS** dataset (also 1998-2010) is available for comparison.

+ Many of the industries are comparable to those in the **BLS MFP** estimates.

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Road Map

+ **Background of MFP development and statistical estimates for the U.S.**
  + Brief History
  + MFP in the IO framework
  + Capital Measurement Issues
  + Published data for the U.S.
+ **Description of Inforum estimates and some results**
  + Overview of LIFT
  + Building KLEMS Accounting into LIFT
  + A Look at Our Estimates
  + Discussion of Measurement Issues
+ **Conclusions and Next Steps**

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MFP: Curriculum Vitae

Growth Theory — 1

Thomas R. Malthus
1766-1834

Monograph Efficiency	9.6
Marginal Rate of Reference	2.0
Public Perception Indicator	8.3
Productivity Potential Index	-167.0
Expected Utility	1.0

Growth Theory — 2

Robert M. Solow
*1924

Monograph Efficiency	8.2
Marginal Rate of Reference	65.0
Public Perception Indicator	4.8
Productivity Potential Index	+8.2
Expected Utility	2.0

MFP Defined

$$MFP = \frac{Q}{I}$$

Q = Real output
I = Real input

If the growth in input and growth in output are equal, there is no MFP growth.

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2 Main Versions of MFP

1. Output = Real value added, inputs = K, L -> *More common, low data requirements*

2. Output = Real gross output, inputs = K,L,E,M,S -> *More KLEMS data becoming available, for U.S., and internationally*

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A Productivity Index

If we use only K and L, with w the wage, and r the capital cost:

$$pQ = wL + rK$$

In base year prices, we can write:

$$p_0 Q_t = S_t [w_0 L_t + r_0 K_t]$$

Where S is an index of output over input.

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Solow: Production Function and Residual

Production function with shift parameter:

$$Q_t = A_t F(K_t, L_t)$$

If each input is paid its marginal product:

$$\frac{\partial Q}{\partial K} = \frac{r_t}{p_t} \quad and \quad \frac{\partial Q}{\partial L} = \frac{w_t}{p_t}$$

The residual can be calculated as:

$$\mathfrak{R}_t = \frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - s_t^K \frac{\dot{K}_t}{K_t} - s_t^L \frac{\dot{L}_t}{L_t}$$

where the *s* are cost shares of nominal output (value added in this model). This is an example of a *Tornqvist Index*.

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MFP in the Input-Output Framework

Use gross output for Q. Divide intermediate purchases into energy(E), materials (M) and services (S):

$$Q_t = A_t F(K_t, L_t, E_t, M_t, S_t)]$$

Now the residual (MFP) can be calculated as:

$$\Re_t = \frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - s_t^K \frac{\dot{K}_t}{K_t} - s_t^L \frac{\dot{L}_t}{L_t} - s_t^E \frac{\dot{E}_t}{E_t} - s_t^M \frac{\dot{M}_t}{M_t} - s_t^S \frac{\dot{S}_t}{S_t}$$

And we can make this calculation for each industry.

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The Measurement of Capital

- Output measurement and the deflation of output pose severe problems.

- Capital is the most difficult input to measure.

- Capital input should be *flow of services*

- In practice we must use an estimated stock, but we can make the flows proportional to elements of the stock.

- Different asset lives imply different speeds of 'using up' capital.

Review of U.S. Data: BEA

Industry Accounts

- Gross Output (426): Output, Revenue, Prices
- GDP by Industry or Value Added (65 sectors)
- KLEMS: Detailed Annual Purchases (EMS)
- Benchmark and Annual Input-Output Accounts

Investment/**Fixed Assets** by type and purchasing industry.

National Income and Product Accounts

- Value added
- Employment and hours

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Review of U.S. Data: BLS

+ **Major Sector Productivity Program**
  + Private Business and Private Nonfarm Business (Real value added on K,L)

+ **Manufacturing Productivity Program**
  + 18 NAICS 3-digit manufacturing industries. (Real gross output on K,L,E,M,S)
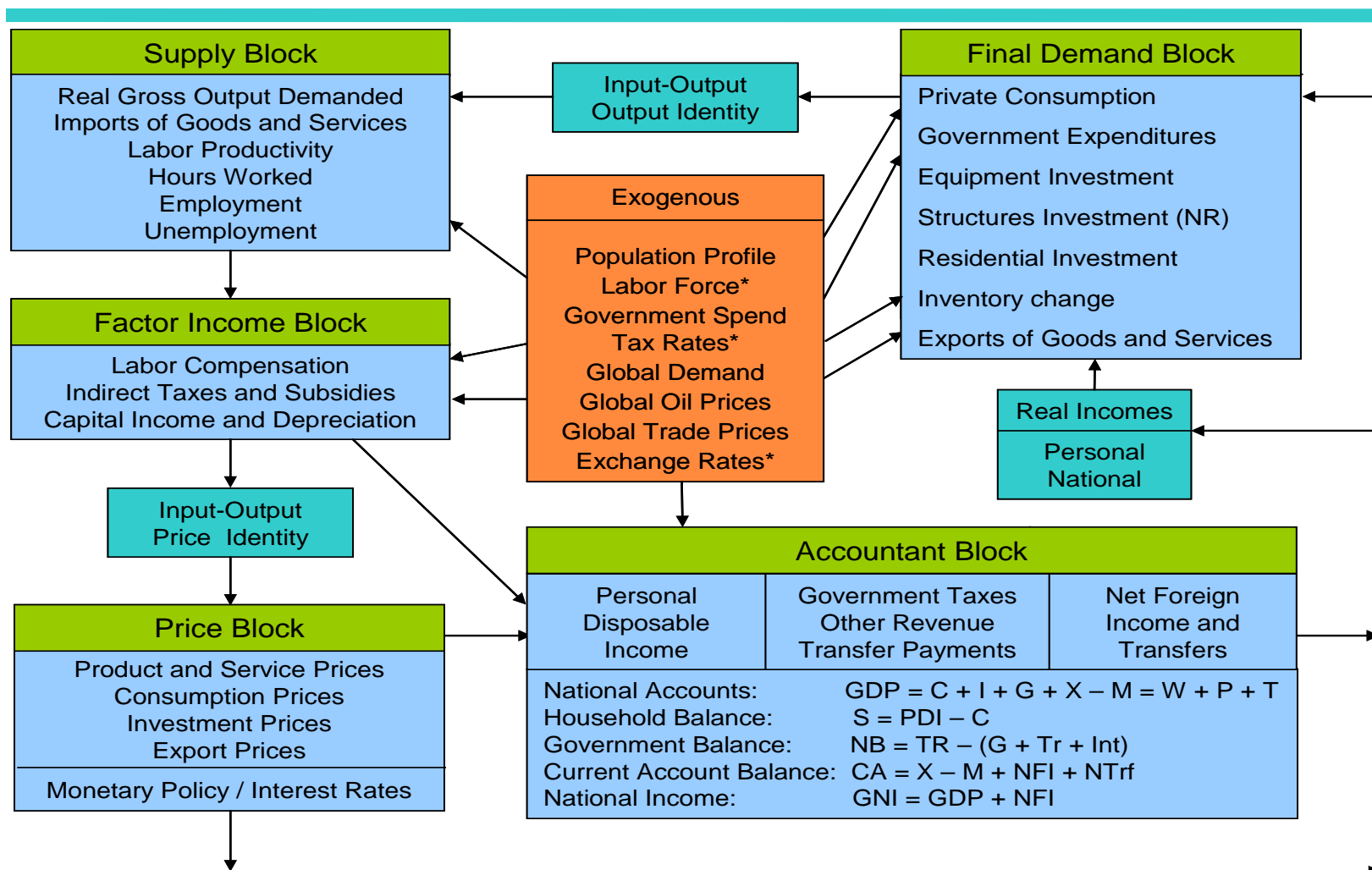
+ **Industry Productivity Program**
  + 86 NAICS 4-digit manufacturing industries, air transportation and railroads. (Real gross output on K,L,E,M,S)

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Incorporation of MFP into *LIFT*

Overview of *LIFT*

➤ Inforum Interindustry Macro (IM) model, builds macro from bottom-up.

➤ 110 commodities (final demands, output and prices) and 65 industries (employment, investment, value added)

➤ LIFT includes a time series of IO tables from 1998-2010.

➤ Benchmark 2002 IO table provides the groundwork.

➤ This is updated with the 1998-2010 Annual IO, along with time series of detailed output, exports and imports

➤ Output and price are both solved using Gauss-Seidel.

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LIFT : One View

Supply Block

Real Gross Output Demanded
Imports of Goods and Services
Labor Productivity
Hours Worked
Employment
Unemployment

Input-Output Output Identity

Final Demand Block

Private Consumption

Government Expenditures

Equipment Investment

Structures Investment (NR)

Residential Investment

Inventory change

Exports of Goods and Services

Exogenous

Population Profile
Labor Force*
Government Spend
Tax Rates*
Global Demand
Global Oil Prices
Global Trade Prices
Exchange Rates*

Factor Income Block

Labor Compensation
Indirect Taxes and Subsidies
Capital Income and Depreciation

Real Incomes

Personal
National

Input-Output Price Identity

Price Block

Product and Service Prices
Consumption Prices
Investment Prices
Export Prices

Monetary Policy / Interest Rates

Accountant Block

Personal Disposable Income	Government Taxes Other Revenue Transfer Payments	Net Foreign Income and Transfers

National Accounts: GDP = C + I + G + X − M = W + P + T
Household Balance: S = PDI − C
Government Balance: NB = TR − (G + Tr + Int)
Current Account Balance: CA = X − M + NFI + NTrf
National Income: GNI = GDP + NFI

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Building KLEMS into *LIFT*

+ *LIFT* contains all the ingredients necessary to estimate a KLEMS-based MFP estimate:

  + Industry Output, in current and constant prices

  + Detailed IO tables in current and constant prices, from which Energy, Materials and Services can be aggregated.

  + Hours worked by industry, labor compensation by industry

  + Capital investment and capital stocks by industry. Capital share is derived as a residual.

+ New vectors and matrices were added for the KLEMS module. Historical estimates of MFP by industry were calculated in *G7*.

+ MFP.cpp was written to do the parallel calculations in the forecast.

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Review of Tornqvist Calculation

1. *Calculate Cost Shares*

$$s_{it}^E = \frac{EN_{it}}{QN_{it}}, s_{it}^M = \frac{MN_{it}}{QN_{it}}, s_{it}^S = \frac{SN_{it}}{QN_{it}}, s_{it}^L = \frac{LAB_{it}}{QN_{it}},$$

$$s_{it}^K = 1 - s_{it}^E - s_{it}^M - s_{it}^S - s_{it}^L$$

$$\bar{s}_{it}^j = \frac{s_{it}^j + s_{i,t-1}^j}{2}$$

2. *Calculate growth of MFP (A)*

$$gr(A) = gr(Q) - \bar{s}_{it}^K gr(K) - \bar{s}_{it}^L gr(L) - \bar{s}_{it}^E gr(E)$$
$$- \bar{s}_{it}^M gr(M) - \bar{s}_{it}^S gr(S)$$

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Cost Shares

- **Total Private Industry**: Value added in 2010 is 54%, with 27% labor compensation, and 22.5% capital.

- **Goods Industries:** 31% value added share, with 20% compensation, and 9.6% capital. Higher share of materials, lower share of purchased services.

- **Services Industries:** Higher labor share, and higher share of purchased services.

- **Services Purchases**: Increasing from 1998-2010, partly due to outsourcing. At the same time, services share of output has increased.

- Cost shares vary widely across industries.

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Components of Gross Output by Major Sector

	1998	2000	2003	2005	2007	2010
All Industries	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Value added	54.7	53.4	54.8	52.8	52.0	53.9
Compensation of employees	28.4	28.6	28.7	27.3	27.1	27.2
Taxes on production	4.3	4.0	4.3	4.2	4.2	4.3
Gross operating surplus	22.0	20.8	21.7	21.3	20.7	22.5
Intermediate inputs	45.3	46.6	45.2	47.2	48.0	46.1
Energy	1.7	2.3	1.9	2.3	2.3	2.0
Materials	17.9	17.2	15.7	17.1	17.5	16.1
Purchased services	25.7	27.1	27.7	27.8	28.2	28.0
Private goods-producing Industries	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Value added	36.1	34.5	35.5	31.9	30.0	31.1
Compensation of employees	22.3	22.9	23.2	20.6	19.9	19.9
Taxes on production	1.0	0.9	1.2	1.1	1.3	1.6
Gross operating surplus	12.8	10.7	11.1	10.1	8.8	9.6
Intermediate inputs	63.9	65.5	64.5	68.1	70.0	68.9
Energy	2.3	3.1	2.7	3.6	3.4	3.0
Materials	40.0	39.8	38.5	41.3	43.1	42.7
Purchased services	21.6	22.6	23.3	23.3	23.5	23.2
Private services-producing Industries	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Value added	64.8	62.9	63.4	62.6	62.2	63.2
Compensation of employees	31.7	31.4	31.2	30.4	30.4	30.1
Taxes on production	6.0	5.6	5.7	5.7	5.6	5.4
Gross operating surplus	27.1	25.9	26.5	26.5	26.3	27.7
Intermediate inputs	35.2	37.1	36.6	37.4	37.8	36.8
Energy	1.4	1.9	1.5	1.8	1.7	1.6
Materials	5.9	5.8	5.5	5.7	5.6	5.3
Purchased services	27.9	29.4	29.7	29.9	30.4	29.9

Components of Output: Selected Industries (%)

	3 Oil and gas extraction	28 Retail trade	59 Accomodation	15 Chemical products	55 Hospitals, nursing, residential care	21 Computer and electronic products
Total	100.0	100.0	100.0	100.0	100.0	100.0
Value added	41.4	69.7	63.7	23.7	60.8	27.6
Compensation of employees	12.0	41.2	38.1	13.9	50.8	34.3
Taxes on production	11.3	14.9	12.2	1.1	2.1	1.6
Gross operating surplus	18.1	13.6	13.4	8.8	7.8	-8.3
Intermediate inputs	58.6	30.3	36.3	76.3	39.2	72.4
Energy	4.1	1.2	3.0	7.7	1.5	0.6
Materials	16.5	3.1	4.3	41.3	9.2	33.7
Purchased services	38.0	25.9	28.9	27.2	28.5	38.1

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Historical Estimates of MFP by Industry

- Example: Chemicals (NAICS 325)
- Table: Output growth (top), Input growth, productivity ratios (middle), and MFP growth (bottom)
- Real output has grown slowly (0.1%) over the period 1998-2010, with a steep drop (-6%) between 2007 and 2010.
- From 2007-2010 some inputs dropped even more than output (energy, materials), so productivity of these inputs increased. Labor and services did not fall by nearly as much as output, and capital continued to increase.
- MFP growth in the bottom line is a weighted average of the productivity growth of each inputs.
- The graphs compare Inforum estimates with BLS.

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Example Industry: Chemicals

	1998-2001	2001-2007	2007-2010	1998-2010
Output	-0.4	3.4	-6.0	0.1
Inputs				
(K) Capital stock	2.3	0.3	1.7	1.2
(L) Labor hours	-2.0	-1.3	-2.8	-1.9
(E) Energy	2.4	0.9	-7.0	-0.7
(M) Materials	-2.2	4.8	-8.1	-0.4
(S) Services	4.4	5.1	-3.8	2.6
Productivity				
(K) Capital stock	-2.7	3.1	-7.5	-1.1
(L) Labor hours	1.6	4.8	-3.3	1.9
(E) Energy	-2.8	2.5	1.1	0.8
(M) Materials	1.8	-1.3	2.4	0.4
(S) Services	-4.7	-1.6	-2.3	-2.5
Multifactor Productivity	-0.8	0.3	-0.4	-0.2

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Comparisons: Inforum and BLS Mfg.

All Manufacturing
Comparison of BLS and Inforum MFP

Durables Manufacturing
Comparison of BLS and Inforum
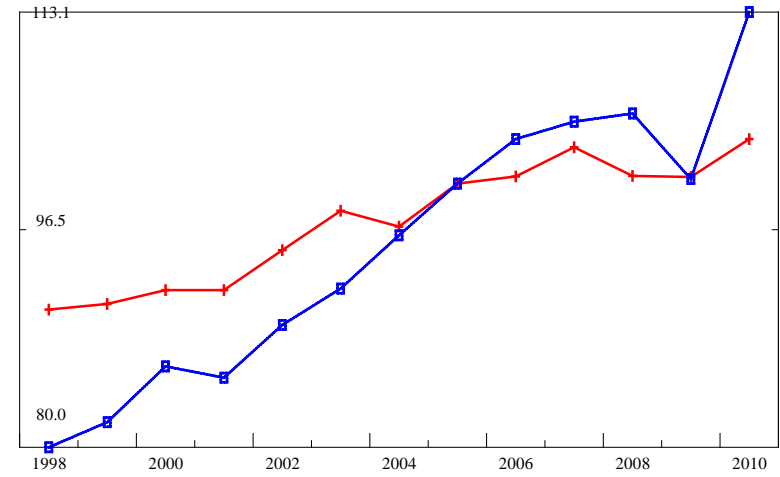
Paper
Comparison of BLS and Inforum
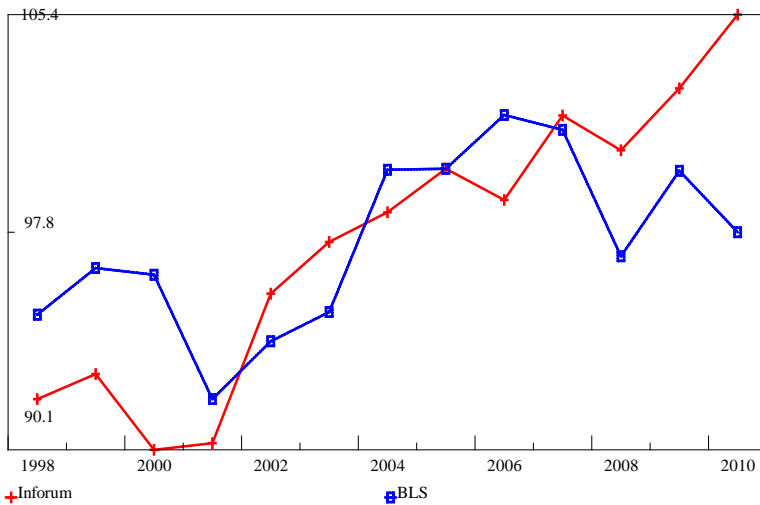
Machinery
Comparison of BLS and Inforum
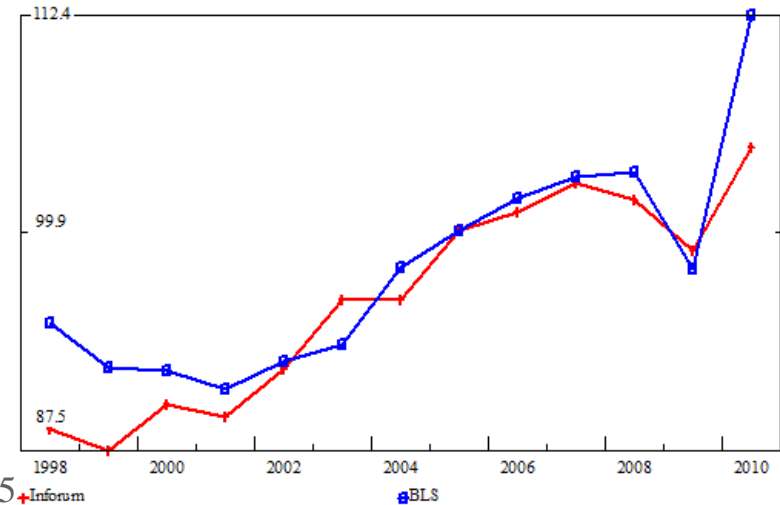
Comparisons: Inforum and BLS Mfg.

Transportation equipment
Comparison of BLS and Inforum
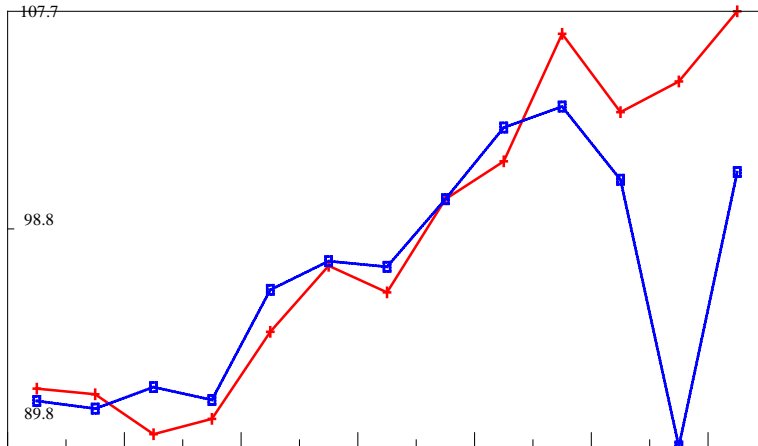
Primary metals
Comparison of BLS and Inforum
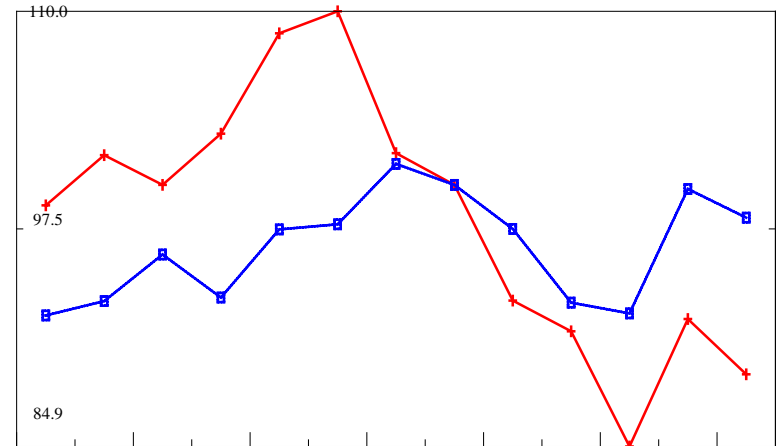
Computers and electronics
Comparison of BLS and Inforum

Chemicals
Comparison of BLS and Inforum

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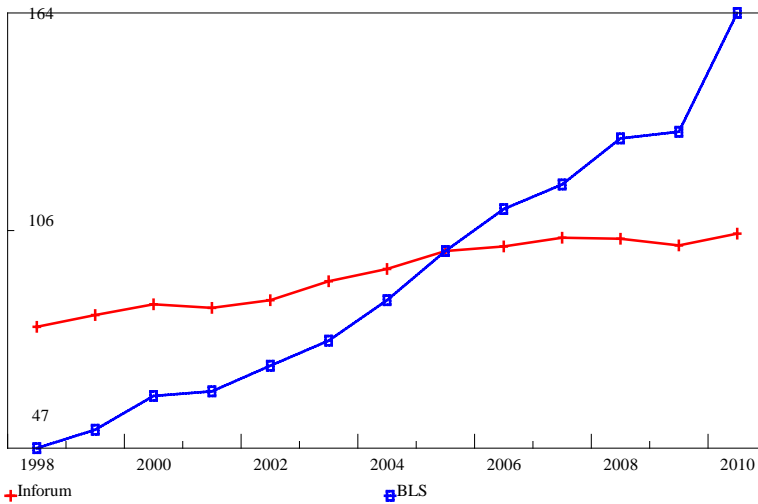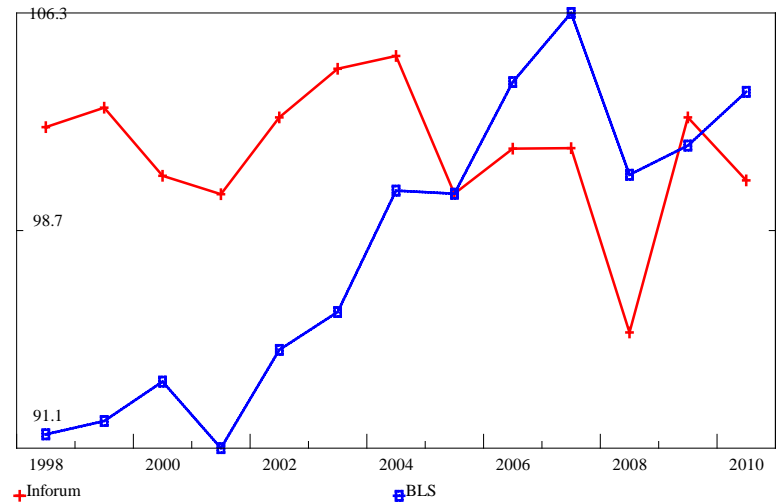
Measurement Issues

+ **Output**: Sectoral vs. gross output. BEA vs. BLS output. How to deflate? (especially computers and related goods)

+ **Capital**: Which types to include? Use economic value or productive capacity? How detailed? Which deflators for investment? Adjust for capacity utilization?

+ **Labor**: How do BLS and BEA estimates of hours compare? Use NIPA share of income, or BLS method?

+ **Energy, Materials and Services**: Inforum is close to BEA KLEMS in nominal data, but different in real terms. BLS maintains its own set of time series of IO. Use producers or purchasers prices for inputs?

+ **Aggregation**: Chained aggregation (Tornqvist or Fisher) or fixed weight?

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Computer Deflator

Computers and electronic products
Output deflator: Inforum vs. BEA
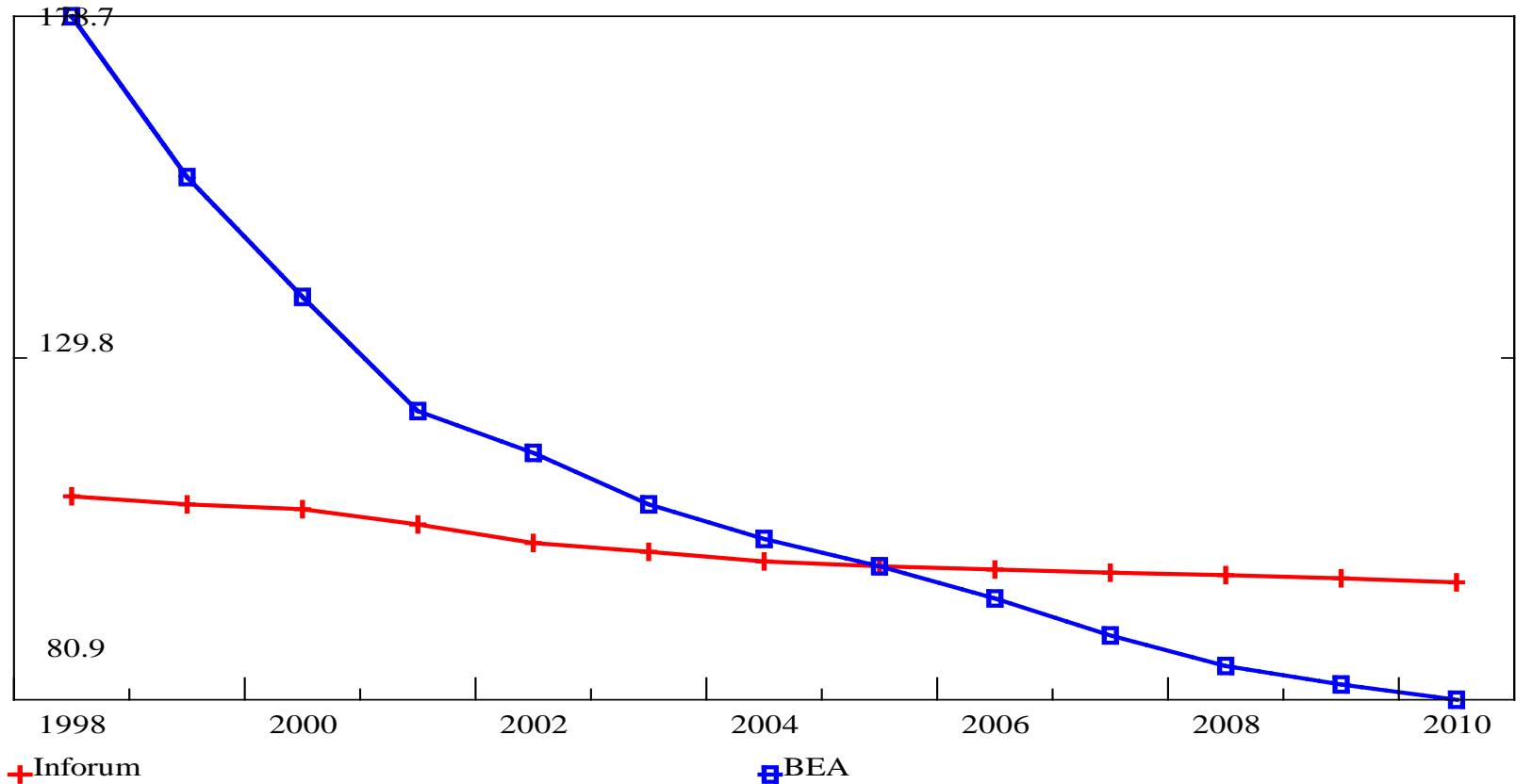
Stock Wearout

Exponential vs. Two-Bucket Capital Stocks
Initial investment of $1 in 1980

+ Exponential   □ TwoBucket

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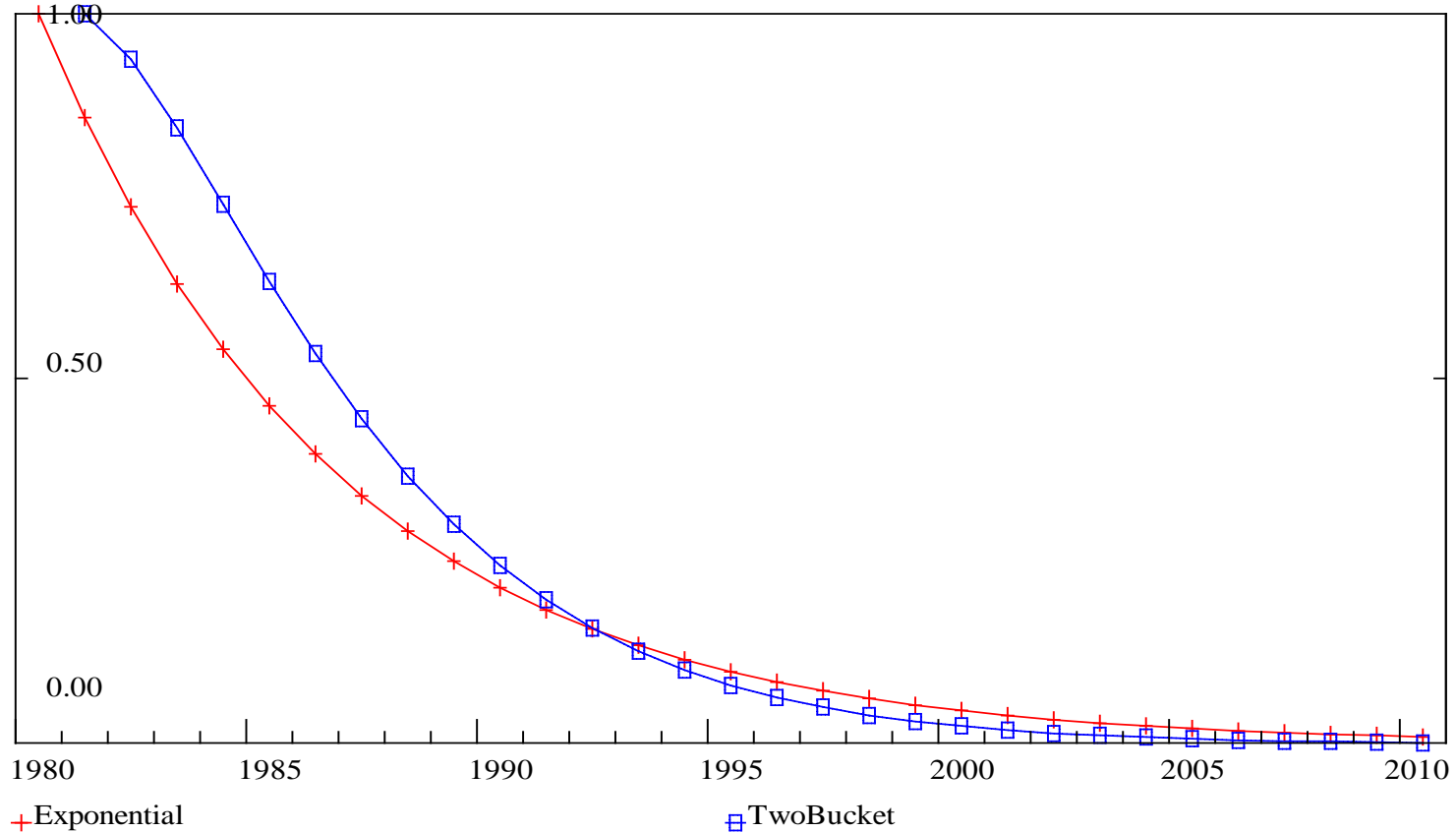
Forecasting MFP

- **Center for Medicare and Medicaid Services**: Want to use forecasts of MFP growth to determine allowable health care price increases.

- **Federal Aviation Administration**: Will look at how MFP in the Air transportation industry affects productivity and costs in other industries.

- **Other Uses**
  - Explore impacts of other variables on MFP, or what changes in labor and capital inputs would achieve a pre-specified MFP growth.
  - Examine forecasts of labor, capital and other factors for reasonableness in light of implied MFP growth.
  - Find link between capital and labor productivity by holding MFP growth rate for an industry fixed.
  - Examine relationships between energy efficiency and MFP, or MFP and price growth.

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Forecast Results

- Forecast MFP is smoother than historically calculated MFP.

- About 20 industries show a similar growth rate to the 1998 – 2010 history.

- Another 20 industries show a significant change in the forecast. Example -> mining sectors had negative growth in the history, but show over 1% in the forecast.

- The remaining industries tend to grow faster than in the historical period, from 0.5 to 1.0 percent.

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Conclusions

- **Goal:** Create a comprehensive and consistent modeling framework for MFP.

- **LIFT Model Database**: Comes close to satisfying the requirements of a set of production accounts.

- **Analysis:** Structural change, outsourcing, changes in imports and exports patterns, labor productivity and price changes.

- **Data Issues:** U.S. decentralized statistical system means that we are faced with conflicting data from BEA and BLS. Inforum contributes its own changes: deflation, IO table purification.

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Extensions and Improvements

+ **Capital Stock:** Form more detailed accounting of capital stock by industry and asset type. Aggregate with chain index.

+ **Labor and Intermediate:** Identify and resolve important differences between Inforum, BEA and BLS MFP.

+ **Scenario Analysis:** Explore implications of faster or slower MFP growth on productivity, prices and investment.

+ **Sectoral Study:** Focus on the health care and air transportation sectors. Identify differences caused by computer deflator measurement problem to establish bounds for correctly measured MFP growth.

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Thank you!

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Additional Materials

Output and KLEMS Inputs: Growth Rates

	1998-2001	2001-2007	2007-2010	1998-2010
All Private Industries				
Output	3.1	2.3	-2.0	1.4
Inputs				
(K) Capital stock	8.2	3.0	-0.4	3.4
(L) Labor hours	0.7	0.8	-2.5	-0.1
(E) Energy	7.4	-4.3	-7.0	-2.2
(M) Materials	-0.8	1.5	-5.2	-0.8
(S) Services	5.5	3.4	-2.2	2.5
Private goods-producing Industries				
Output	-0.3	1.0	-5.4	-1.0
Inputs				
(K) Capital stock	3.0	1.8	-1.2	1.3
(L) Labor hours	-0.8	-0.7	-6.5	-2.2
(E) Energy	4.8	-2.8	-10.5	-3.0
(M) Materials	-1.4	1.7	-6.3	-1.1
(S) Services	2.1	3.1	-5.7	0.6
Private services-producing Industries				
Output	4.9	2.9	-0.6	2.5
Inputs				
(K) Capital stock	11.1	3.5	-0.1	4.4
(L) Labor hours	1.2	1.3	-1.3	0.6
(E) Energy	9.6	-5.5	-3.9	-1.5
(M) Materials	1.5	0.9	-1.9	0.3
(S) Services	6.9	3.5	-1.1	3.2

All Manufacturing
Comparison of BLS and Inforum MFP
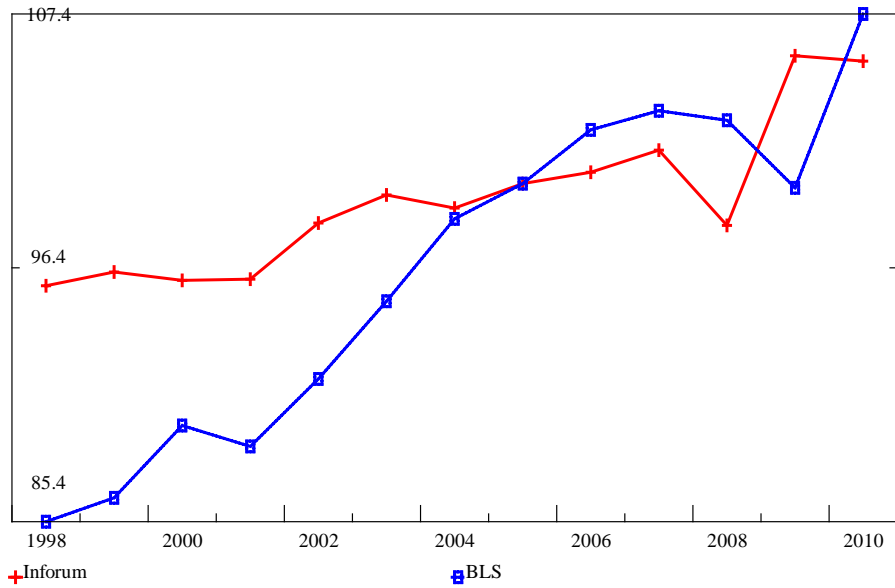
107.4

96.4

85.4

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS

Durables Manufacturing
Comparison of BLS and Inforum

113.1

96.5

80.0

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS

Non Durables Manufacturing
Comparison of BLS and Inforum

110.2

101.8

93.5

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS
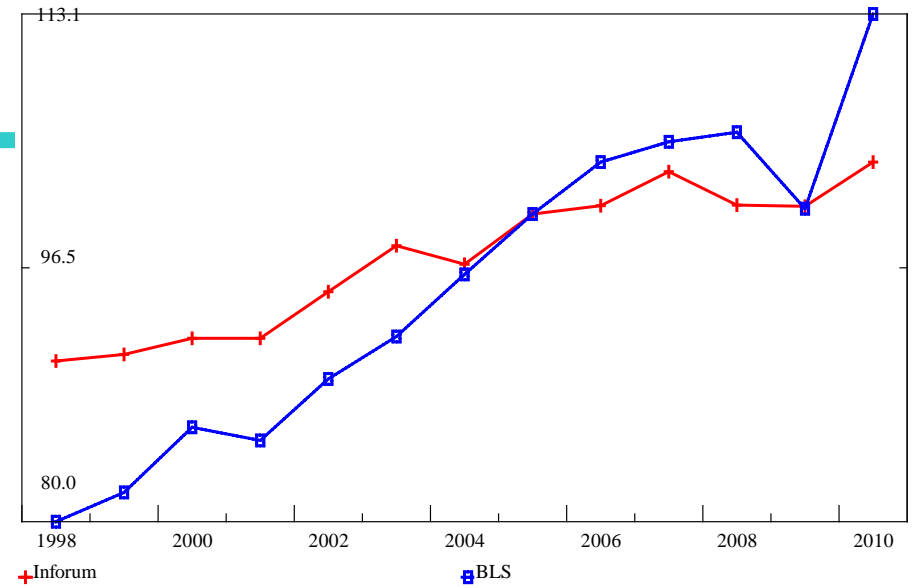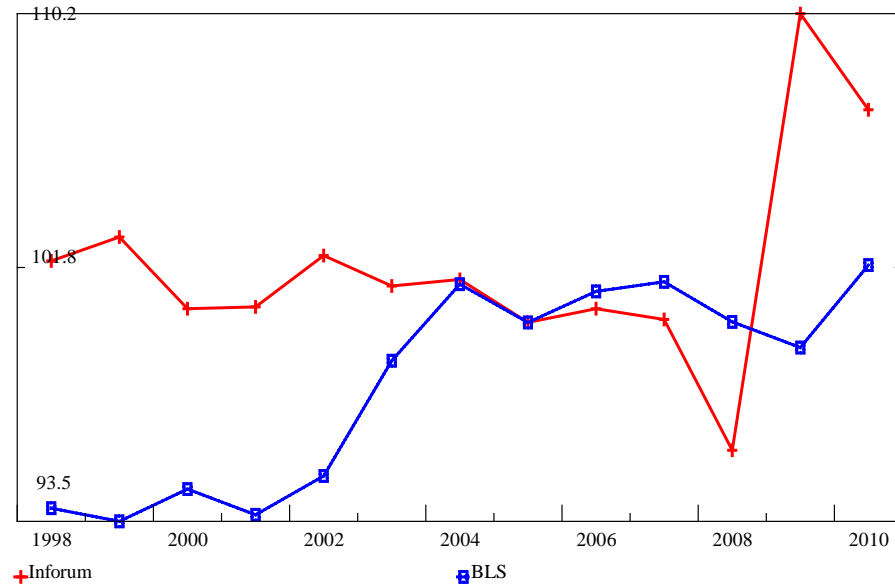
Food, beverages and tobacco
Comparison of BLS and Inforum

104.50

99.98

95.47

1998   2000   2002   2004   2006   2008   2010

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3'

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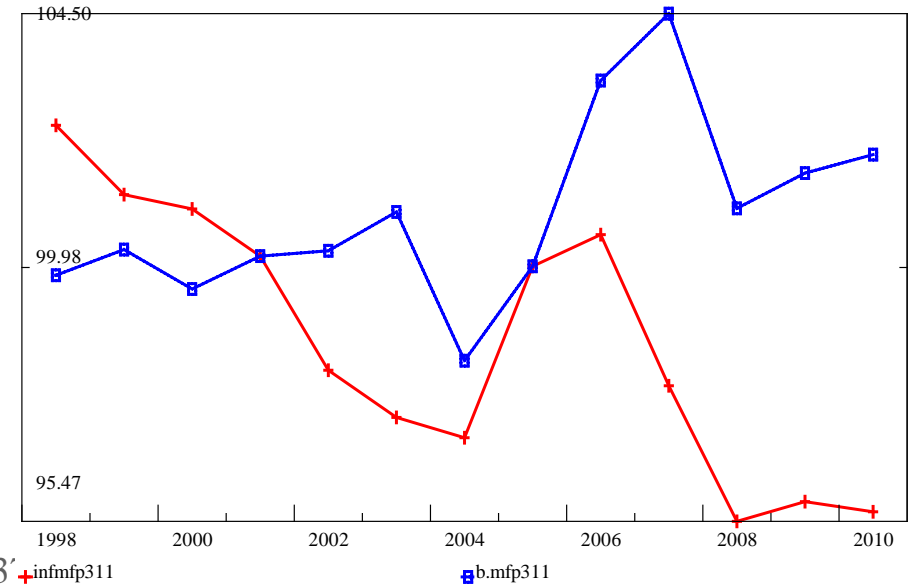
Textiles
Comparison of BLS and Inforum

106.9

93.5

80.1

1998 2000 2002 2004 2006 2008 2010

+ Inforum   □ BLS
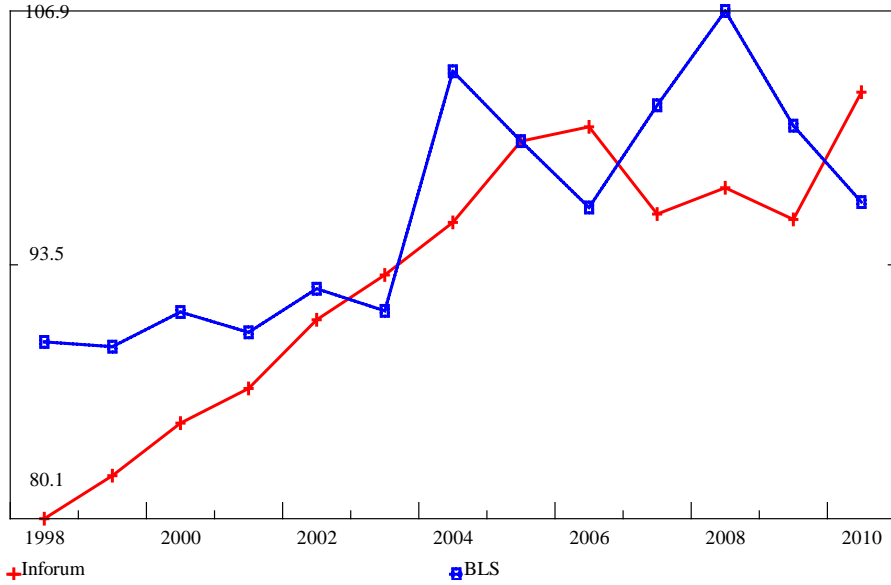
Apparel and leather
Comparison of BLS and Inforum

129.7

105.5

81.3

1998 2000 2002 2004 2006 2008 2010

+ Inforum   □ BLS

Paper
Comparison of BLS and Inforum

105.4

97.8

90.1

1998 2000 2002 2004 2006 2008 2010

+ Inforum   □ BLS

Printing
Comparison of BLS and Inforum

105.0

97.6

90.3

1998 2000 2002 2004 2006 2008 2010

+ Inforum   □ BLS

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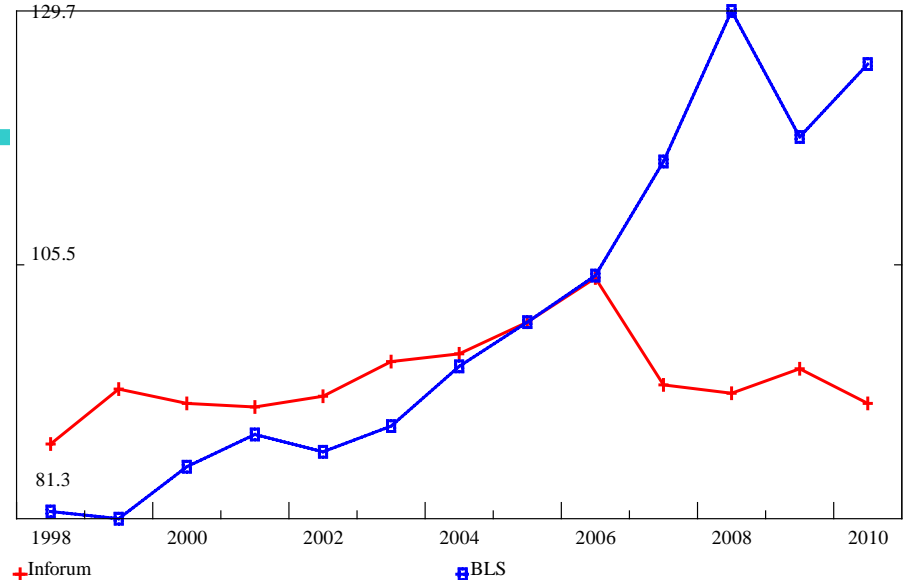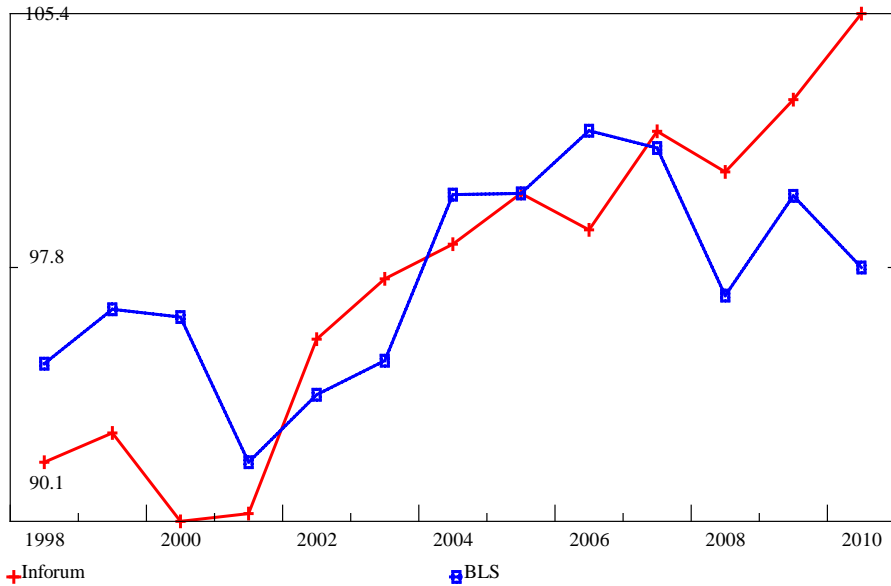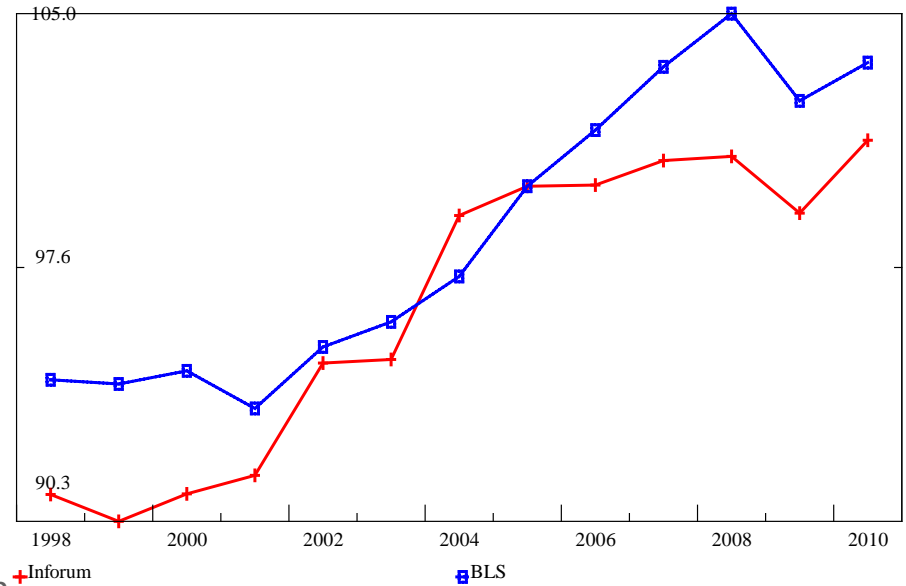
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Petroleum and coal
Comparison of BLS and Inforum

156.7

121.6

86.5

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS

Chemicals
Comparison of BLS and Inforum

106.3

98.7

91.1

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS
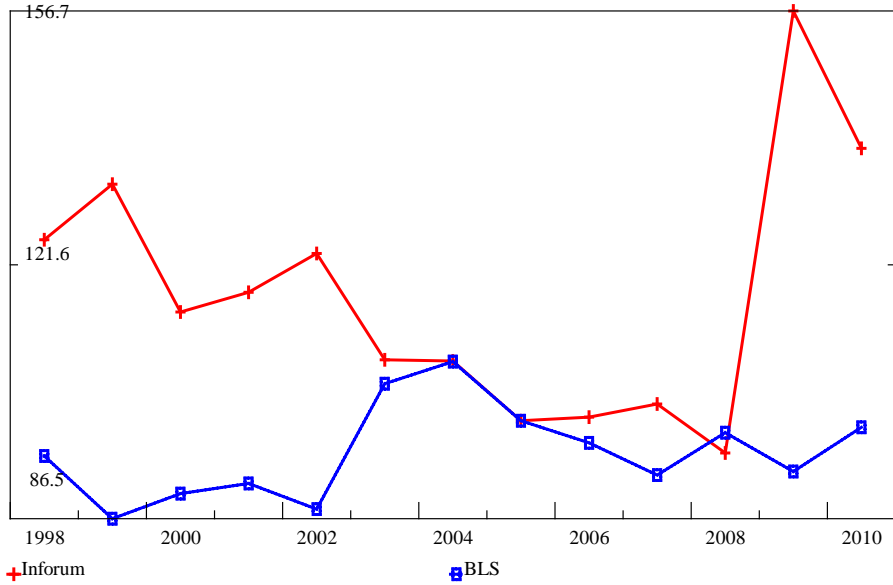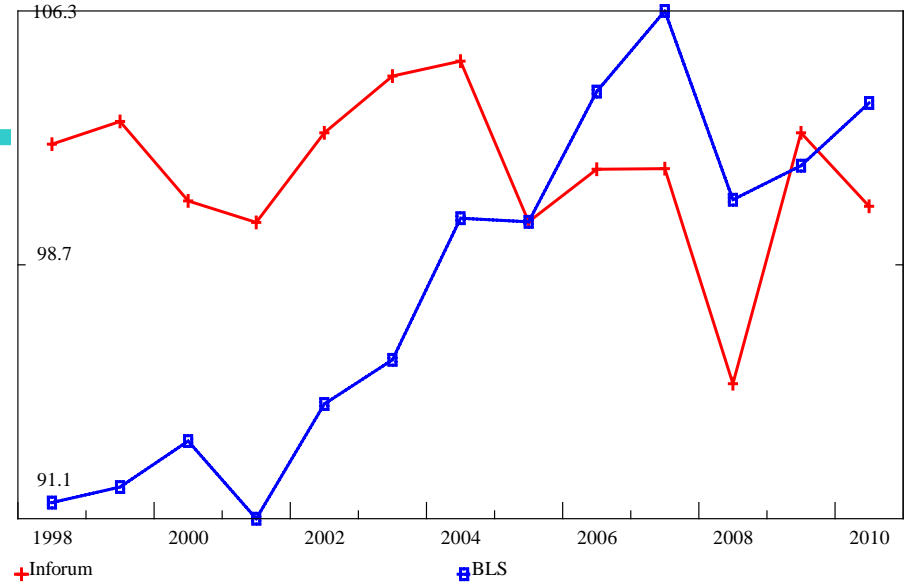
Plastics and rubber
Comparison of BLS and Inforum

104.07

99.18

94.28

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS

Wood products
Comparison of BLS and Inforum

115.0

105.0

95.0

1998   2000   2002   2004   2006   2008   2010

Inforum   BLS
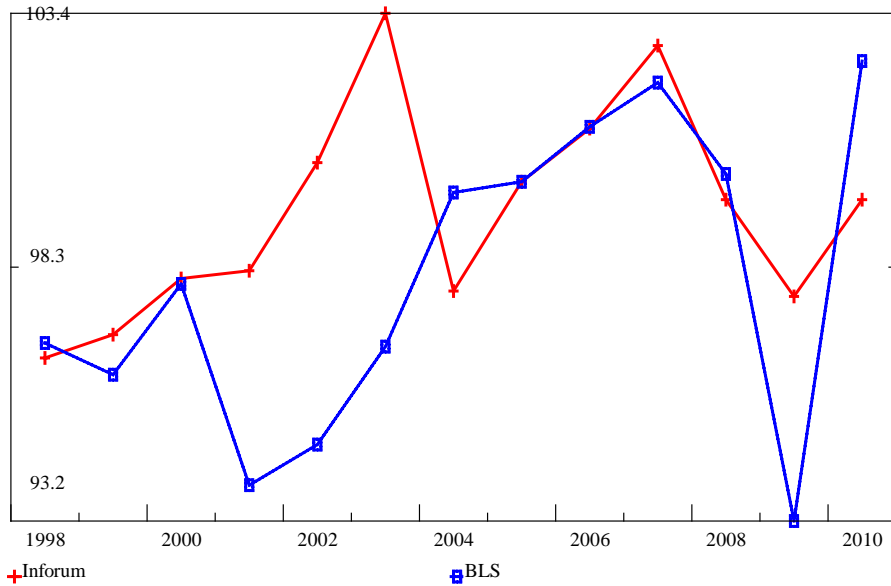
Firenze Conference
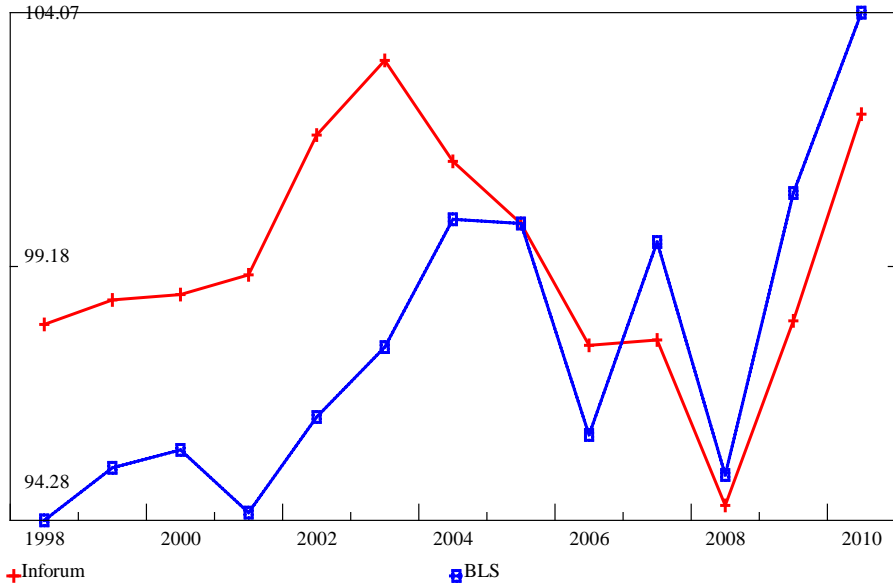
NFUNUM
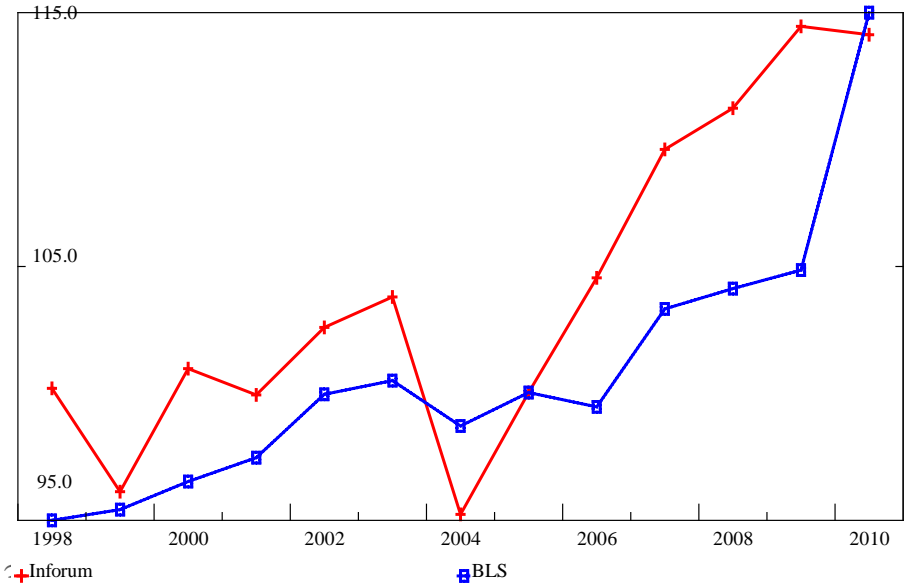
Nonmetallic minerals
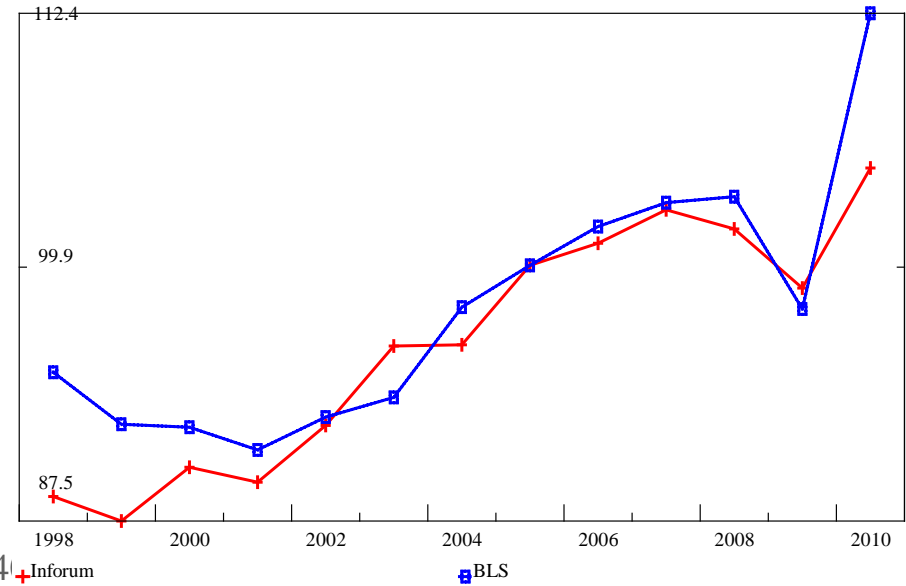### Comparison of BLS and Inforum
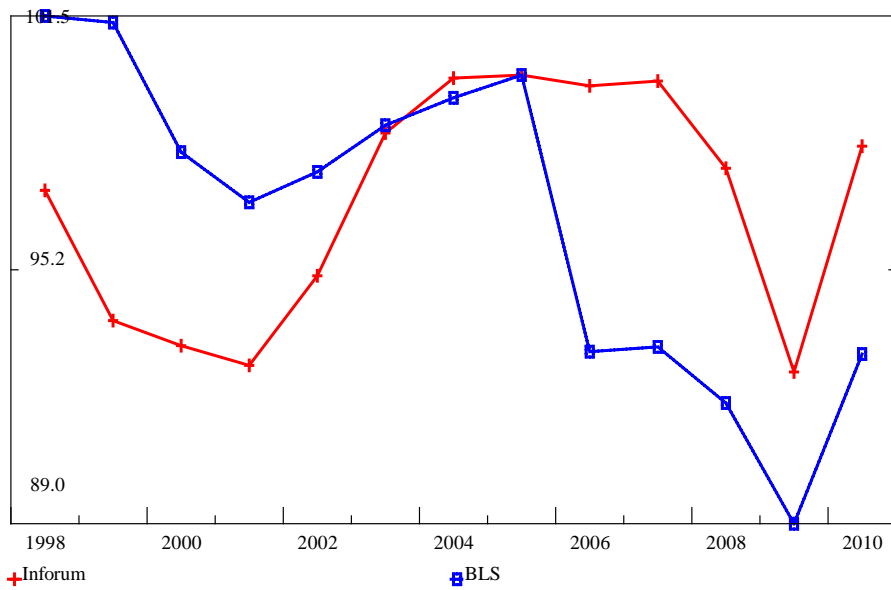
Primary metals
Comparison of BLS and Inforum
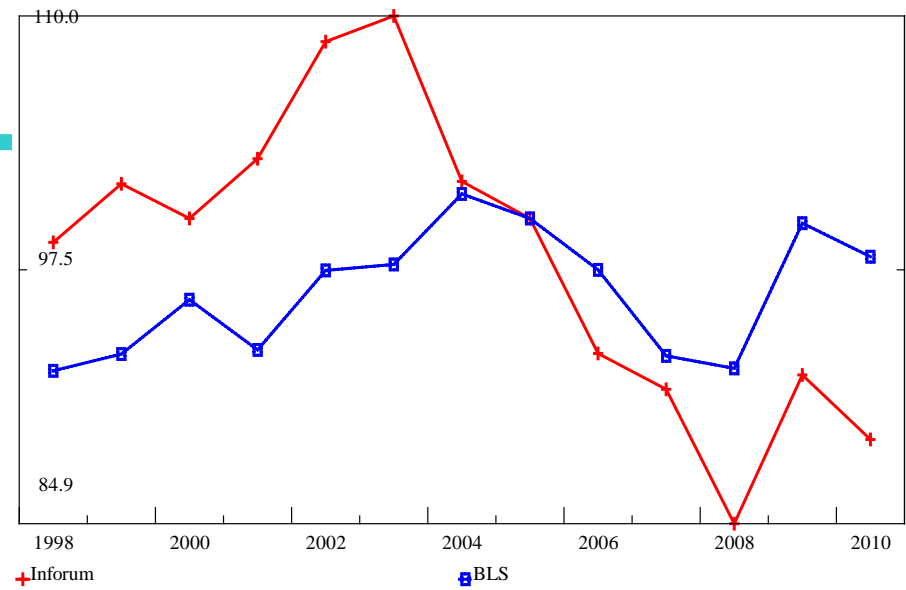
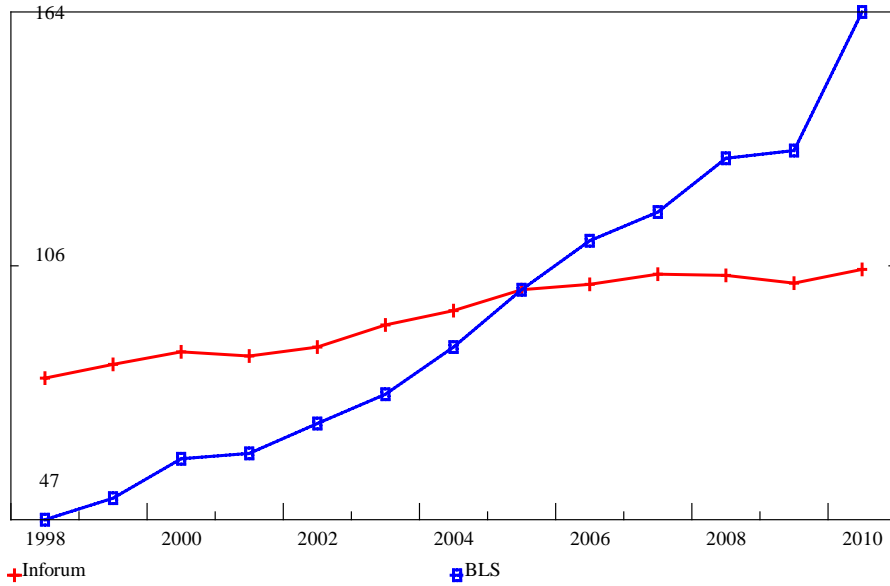## Fabricated metal products
Comparison of BLS and Inforum

Machinery
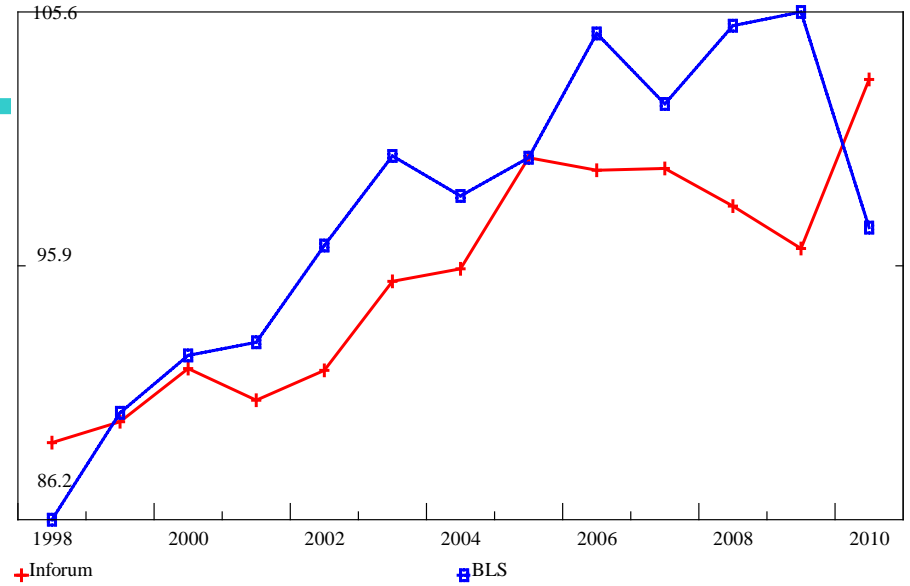### Comparison of BLS and Inforum

Firenze Conference

Computers and electronics
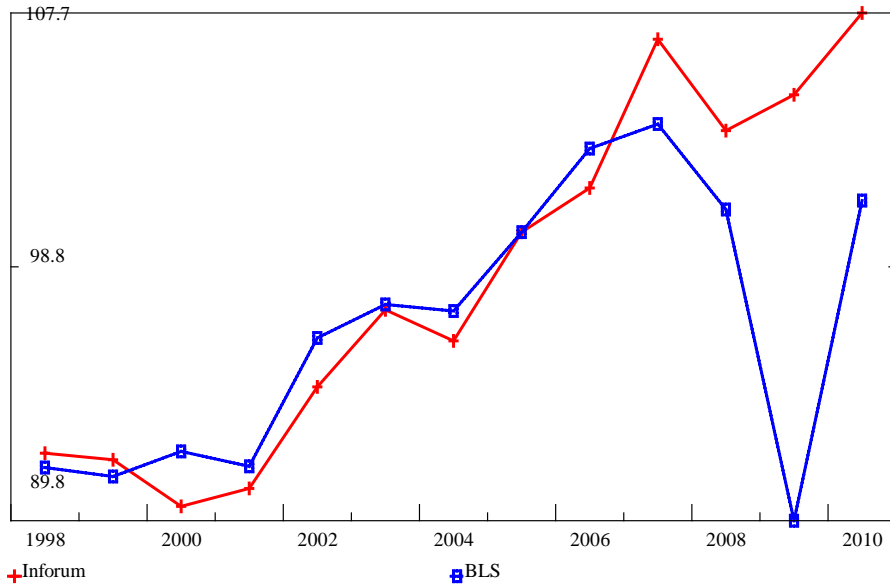## Comparison of BLS and Inforum

Electrical equipment and applicances
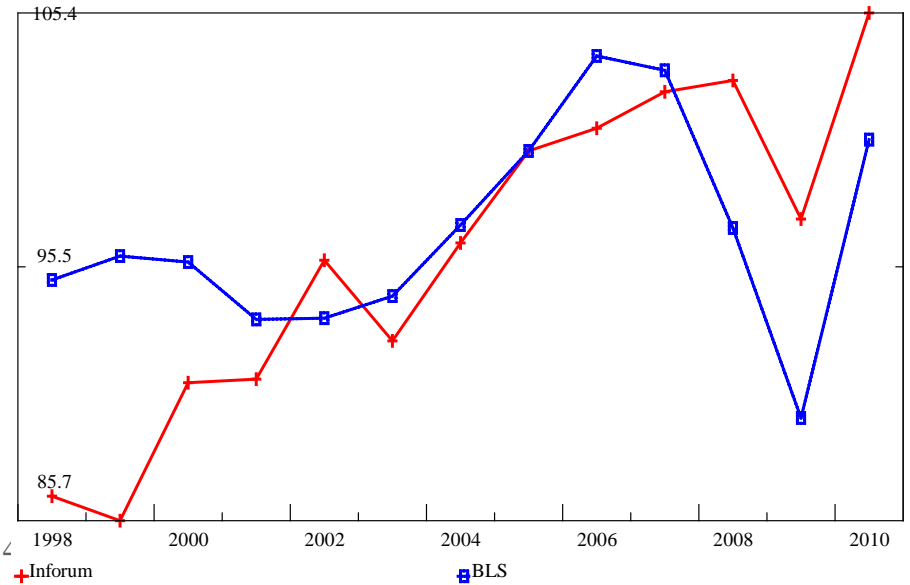## Comparison of BLS and Inforum

Transportation equipment
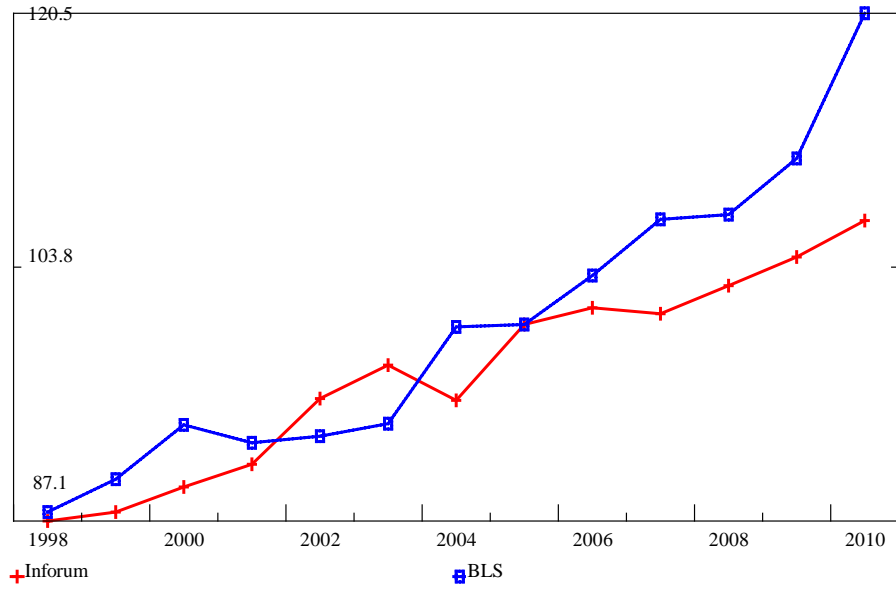## Comparison of BLS and Inforum

Furniture
Comparison of BLS and Inforum

Miscellaneous manufacturing
Comparison of BLS and Inforum

MFP Forecast

	1998-2010	2010-2020	2020-2030
1 Farms	-0.4	0.4	0.4
2 Forestry, fishing, and related activities	-0.3	0.6	0.6
3 Oil and gas extraction	-6.4	1.1	1.2
4 Mining, except oil and gas	-2.0	1.2	1.2
5 Support activities for mining	-0.6	2.7	1.0
6 Utilities	-2.1	1.3	1.1
7 Construction	-1.6	2.2	1.0
8 Food and beverage and tobacco products	-0.6	-0.2	0.0
9 Textile mills and textile product mills	2.1	0.7	0.2
10 Apparel and leather and allied products	0.4	3.3	0.8
11 Wood products	1.1	0.9	0.5
12 Paper products	1.1	0.8	0.8
13 Printing and related support activities	0.9	1.2	1.0
14 Petroleum and coal products	0.8	-0.3	-0.2
15 Chemical products	-0.2	0.1	0.3
16 Plastics and rubber products	0.3	0.3	0.1
17 Nonmetallic mineral products	0.1	1.5	1.1
18 Primary metals	-0.9	0.6	0.5
19 Fabricated metal products	0.3	0.8	0.7
20 Machinery	1.4	0.9	0.8
21 Computer and electronic products	2.3	0.5	0.2
22 Electrical equipment, appliances, and components	1.2	0.3	0.3
23 Motor vehicles, bodies and trailers, and parts	1.6	0.6	0.5
24 Other transportation equipment	0.6	0.8	0.9
25 Furniture and related products	1.6	0.9	0.4
26 Miscellaneous manufacturing	1.7	1.1	0.9
27 Wholesale trade	2.7	2.7	2.1
28 Retail trade	0.9	2.0	1.1
29 Air transportation	0.7	0.8	0.6
30 Rail transportation	0.4	0.7	0.8
31 Water transportation	0.6	1.3	1.1

MFP Forecast

	1998-2010	2010-2020	2020-2030
32 Truck transportation	0.4	1.0	0.7
33 Transit and ground passenger transportation	-1.1	-0.3	-0.4
34 Pipeline transportation	1.7	-0.4	-0.5
35 Other transportation and support activities	1.1	1.2	1.2
36 Warehousing and storage	1.2	1.8	1.6
37 Publishing industries (includes software)	-0.7	2.0	1.7
38 Motion picture and sound recording industries	0.7	1.7	1.1
39 Broadcasting and telecommunications	2.7	1.8	1.7
40 Information and data processing services	4.1	3.3	2.2
41 Federal Reserve banks, credit intermediation	1.5	1.5	1.5
42 Securities, commodity contracts, and investments	2.7	2.0	1.4
43 Insurance carriers and related activities	-0.8	1.6	1.5
44 Funds, trusts, and other financial vehicles	0.4	1.9	1.4
45 Real estate	-0.7	2.3	1.7
46 Rental and leasing services and lessors of intangibles	-0.2	2.9	2.9
47 Legal services	-3.0	1.9	1.9
48 Miscellaneous professional, scientific and technical services	-0.6	1.8	1.8
49 Computer systems design and related services	2.2	3.1	2.5
50 Management of companies and enterprises	-0.3	2.3	1.9
51 Administrative and support services	-0.3	1.7	1.6
52 Waste management and remediation services	-0.8	0.9	1.0
53 Educational services	-1.4	0.7	1.2
54 Ambulatory health care services	0.2	1.7	1.8
55 Hospitals and nursing and residential care facilities	-0.2	1.3	2.0
56 Social assistance	0.3	1.6	1.3
57 Performing arts, spectator sports, museums	0.5	1.6	1.4
58 Amusements, gambling, and recreation	-0.9	1.7	1.4
59 Accommodation	1.7	1.6	1.2
60 Food services and drinking places	0.8	0.9	0.8
61 Other services, except government	-1.8	1.5	1.3