A constrained nonparametric regression analysis of factor-biased technical change and TFP growth at the firm level

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Introduction

- Most calculations of TFP explicitly assume technological change to be Hicks-neutral, in effect, innovation is assumed to increase the marginal productivity of all production factors equally
- Skill-biased technological change (SBTC) is often put forward as the major explanation for the weakened labour market position of the low-skilled
- Capital-augmenting technological change related to the structural increase in the income share of capital
- Some argue there is an overestimation of the TFP slowdown by falsely imposing Hicks neutrality

Introduction

Factor biases due to new technologies

- ICT revolution
- Race against the machine
  - Brynjolfsson and McAfee (2011, 2014)
- Task changes and job polarization
  - Autor, Levy, Murnane (2003, QJE), Autor, Katz and Kearney (2008, REV ECON STAT)
- Implication: skill bias and/or capital bias

Introduction

Factor biases due to internationalization of the production chain

- Trade in tasks
  - Baldwin and Robert-Nicoud (2014,J INT ECON), Grossman and Rossi-Hansberg (2008,AER)
  - Outsourcing, off-shoring, changing role in the global value chain
  - Role for ICT to facilitate outsourcing?
- Implication: skill bias and/or material bias

Introduction

This paper

- We show factor biases are widespread in manufacturing industries in Belgium
- Nonparametric framework: we allow for interactions between the output elasticities and time, without parametrization of the biases a priori
- We highlight technical change that is low-skilled labour-saving and materials-using
- Functional form specification, including Hicks neutrality, considerably impacts TFP change estimates

Outline

1. Introduction
2. TFP growth with Factor-Biased Technical Change (FBTC)
3. Nonparametric framework
4. Firm-level data
5. Results on FBTC and TFP growth
6. Concluding remarks

TFP growth with FBTC

How to measure FBTC?

- Index approach
- Nonparametric linear programming approach
- Econometric approach (mainly translog)

TFP growth with FBTC

How to measure FBTC? Econometric approach

- Translog model
  - Kumbhakar, Heshmati and Hjalmarsson (1999, SJE): interaction between time trend or general technology index and input factors

$$\widehat{TFP_t} = \left[\alpha_t + \alpha_{tt} t + \sum_j \alpha_{jt} lnX_j\right] + (RTS - 1) \sum_j \epsilon_j \frac{\dot{X}_j}{X_j}, \epsilon_j = \frac{\partial lnY}{\partial lnX_j}. \quad (1)$$

  - Zhang (2014): Translog model with productivity as an unobservable component of the production

TFP growth with FBTC

How to measure FBTC? Econometric approach

- Translog can give economically meaningless results and can imply a multicollinearity problem
- CES production function
  - e.g. Klump, McAdam and Willman (2007,ReStud), Dorazelski and Jaumandreu (2012)
- Kumbhakar and Sun (2012, Empirical Economics): Semiparametric varying coefficients model applied to an input distance function
- We: fully nonparametric production function

The production model

Hicks neutrality

- $\forall lnX_j : \partial^2 lnY / \partial lnX_j \partial t = 0$, with $j = 1, .., m$.
- $lnY_i = g(lnX_i) + A(t) + u_i,$ with i=1,...,n.

Factor bias

- Following Binswanger (1974, AER):
  $B_j = \frac{\partial S_j}{\partial t} = \frac{\partial \epsilon_j}{\partial t} = \frac{\partial^2 g}{\partial lnX_j \partial t} \neq 0$, for some j in $1, ..., m$.
- $lnY_i = g(lnX_i, t) + u_i,$ with i=1,...,n.

The production model

Heterogeneity in technology across groups of firms

- Add categorical variables that interact with t and lnX.
- $X^c = [lnX, t]$
- $\tilde{X} = [lnX, t, X^u] = [X^c, X^u]$

General production model

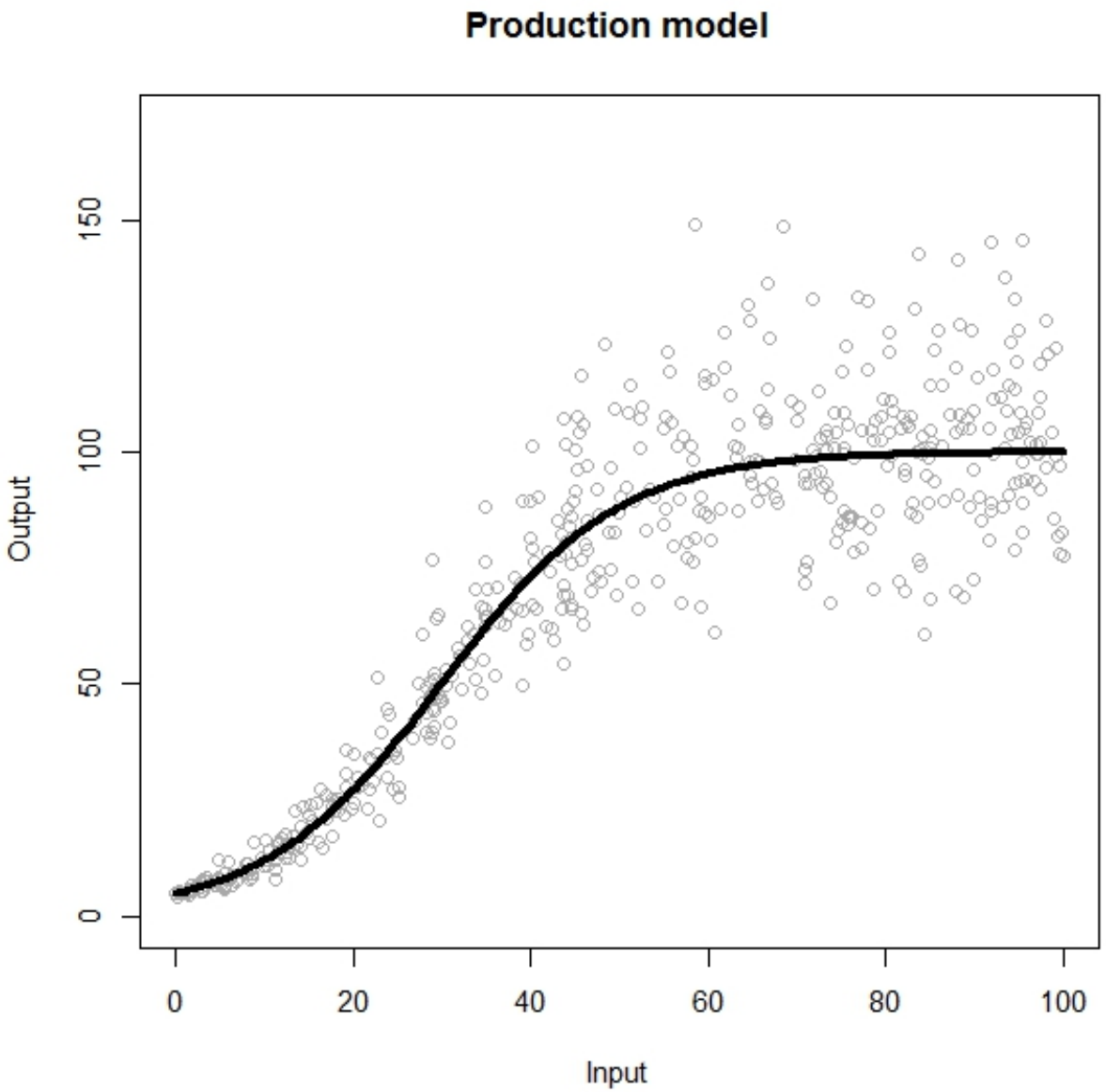
$$lnY_i = g(\tilde{X}_i) + u_i, \text{ with } i = 1, ..., n. \tag{2}$$

Local linear regression

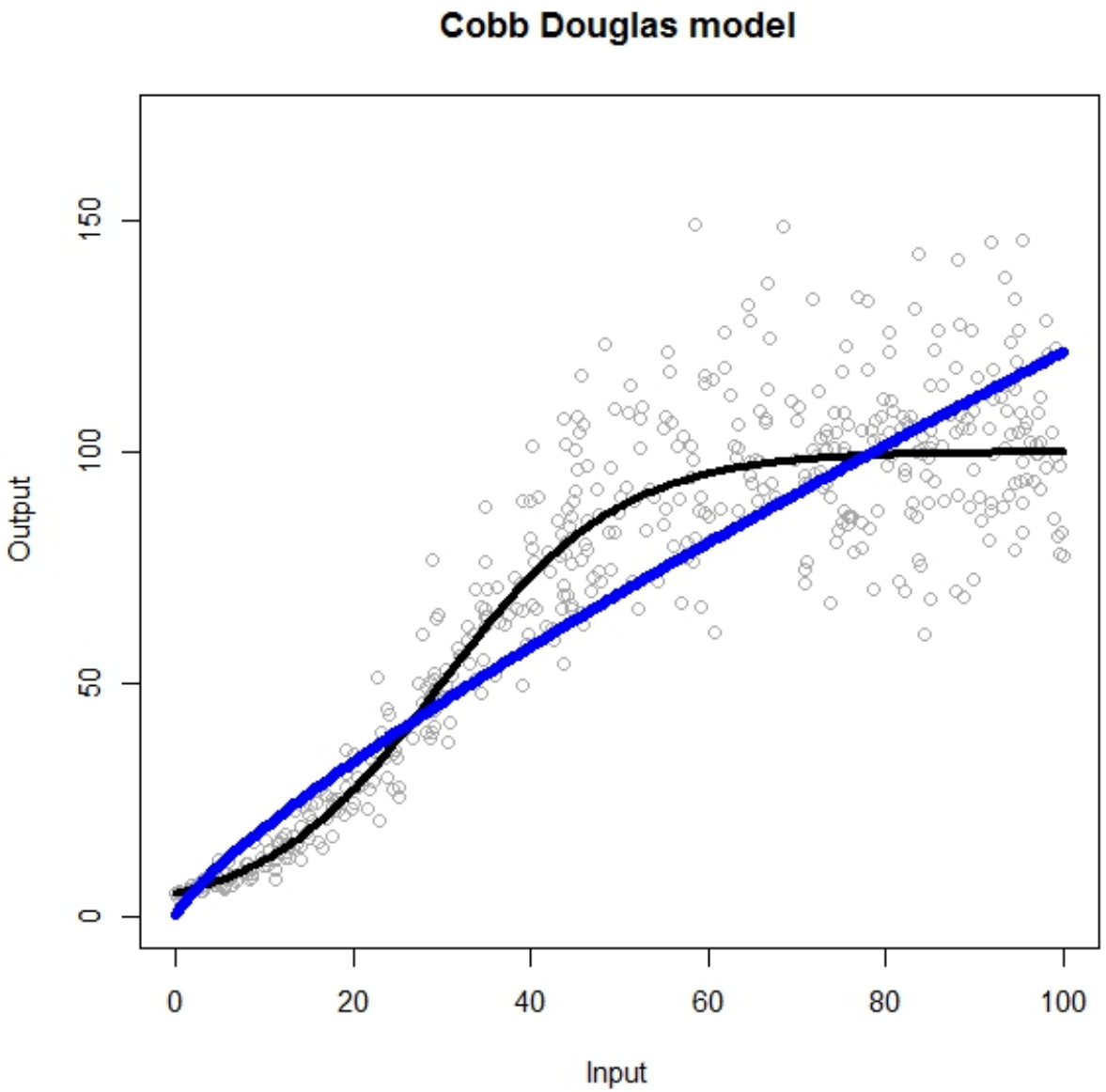
Generalized kernel regression

- Li and Racine (2007, Princeton University Press)
- $E[lnY_i|\tilde{X} = \tilde{X}_i]$ is not parametrized, but estimated by means of a localized regression.
- $\hat{g}(\tilde{X}_i) = E[lnY_i|\tilde{X}$ close to $\tilde{X}_i]$ as an approximation of $E[lnY_i|\tilde{X} = \tilde{X}_i]$
- Parametric least squares estimator as a special case of the local linear estimator
- Least squares cross-validation to choose the optimal level of localization

Illustrative simulation



Illustrative simulation



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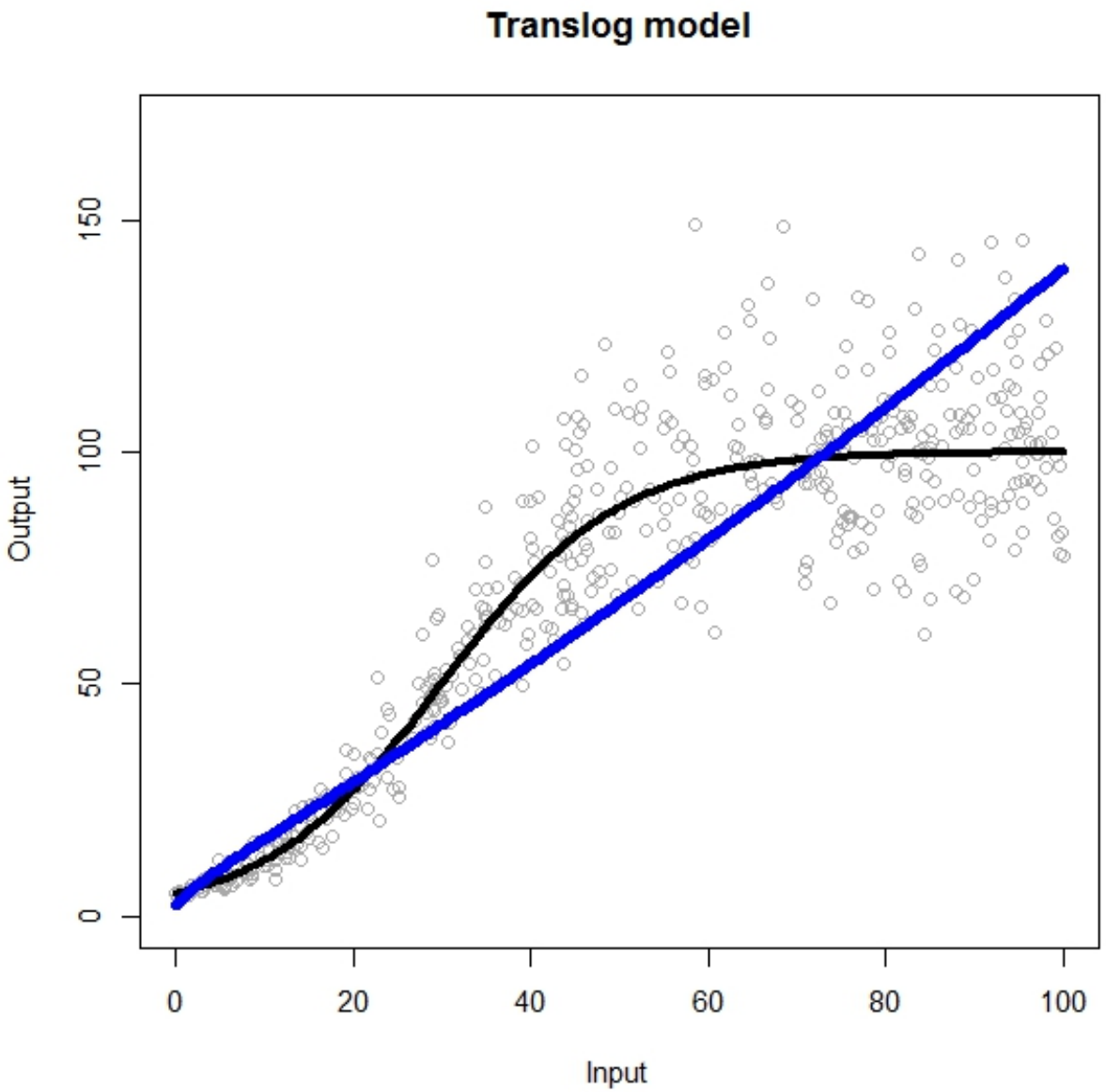

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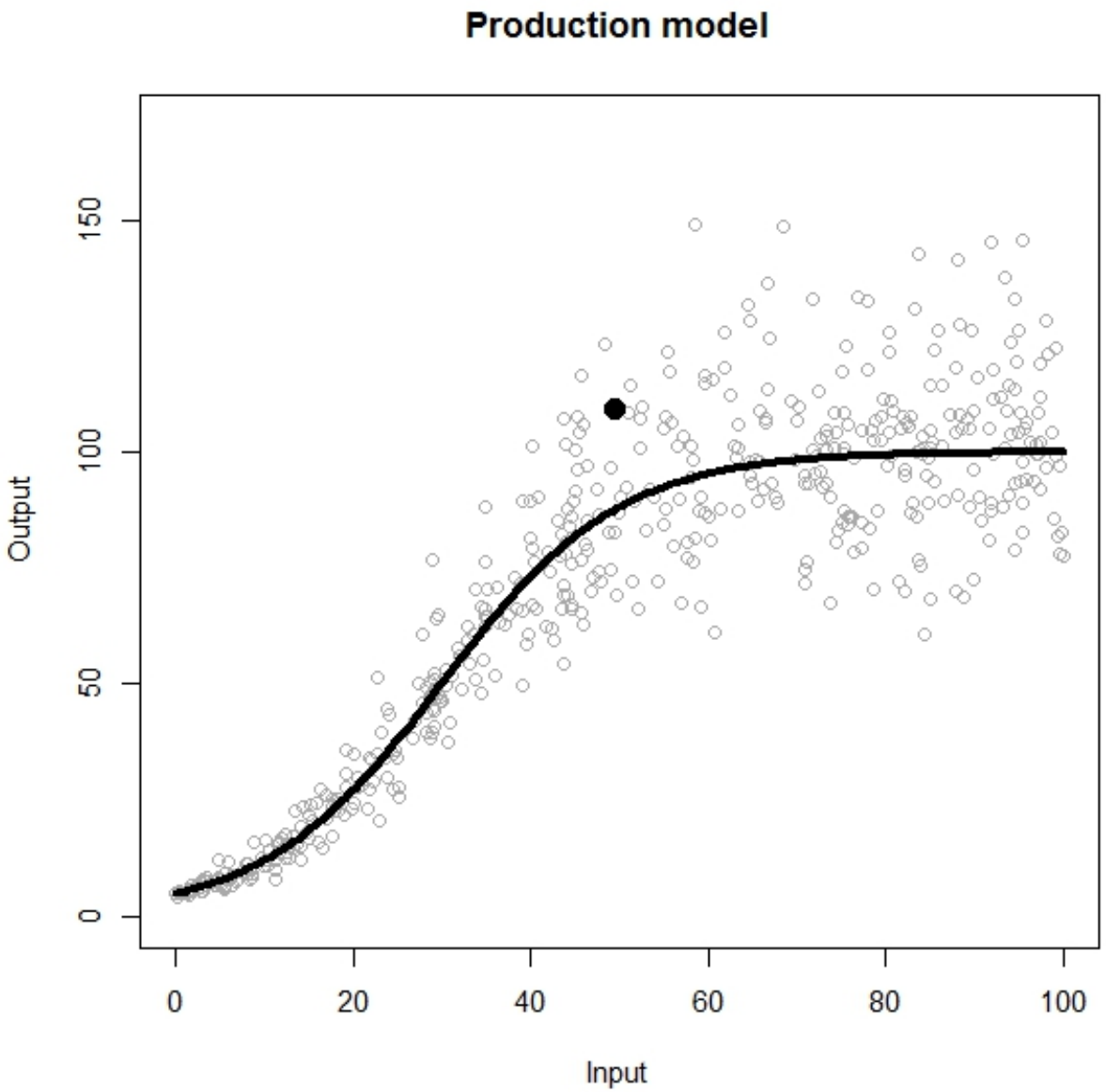

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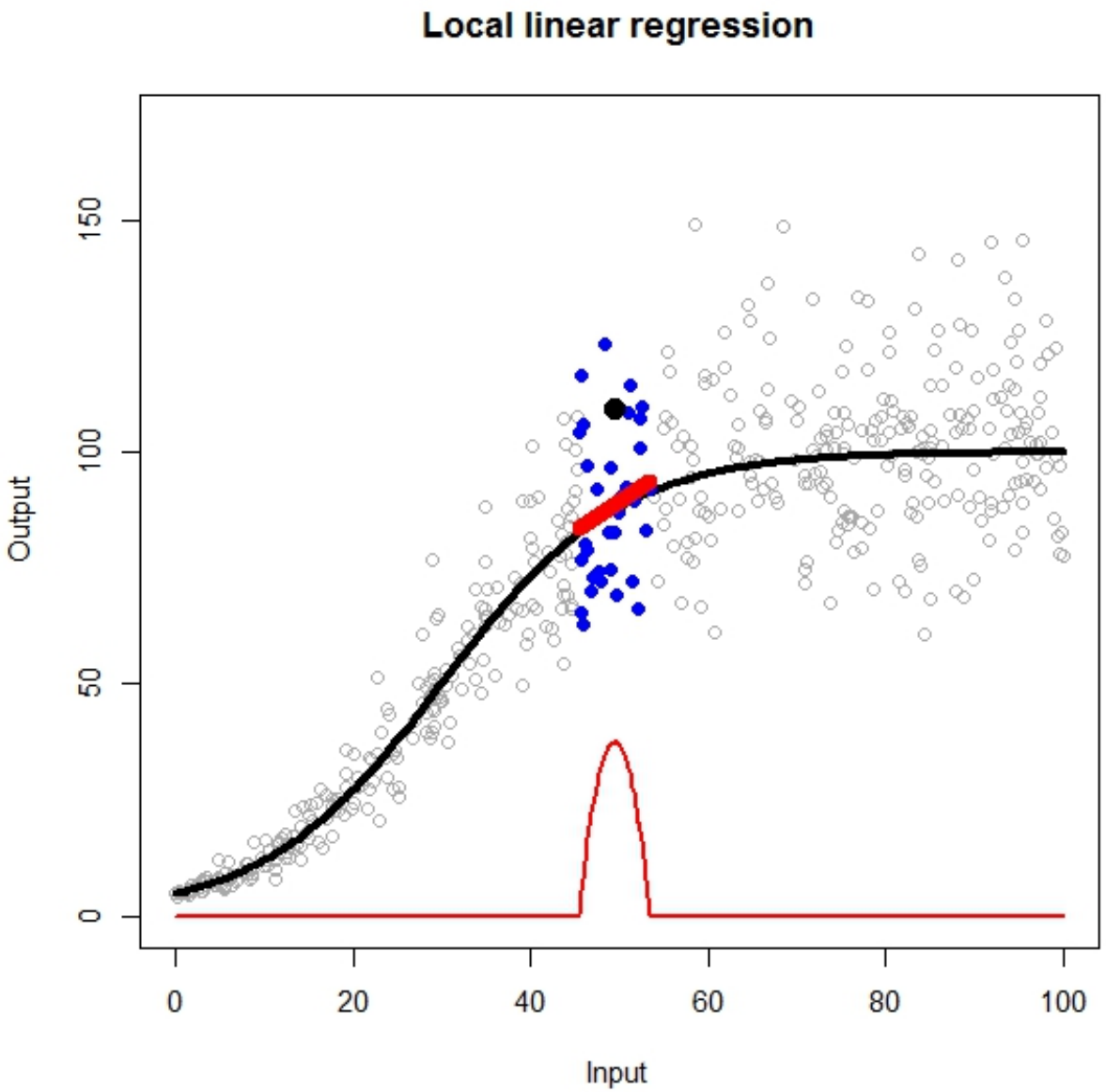

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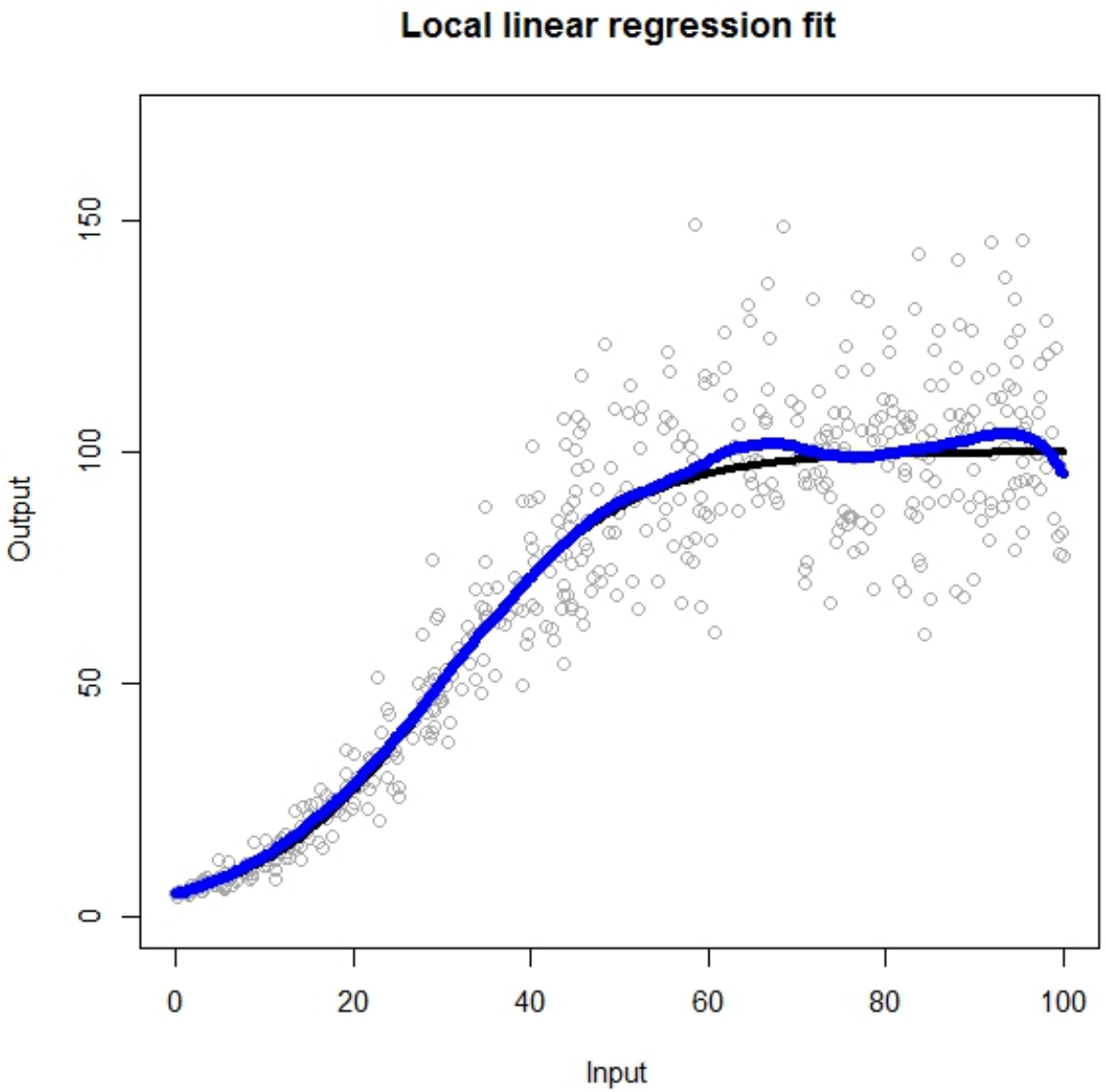

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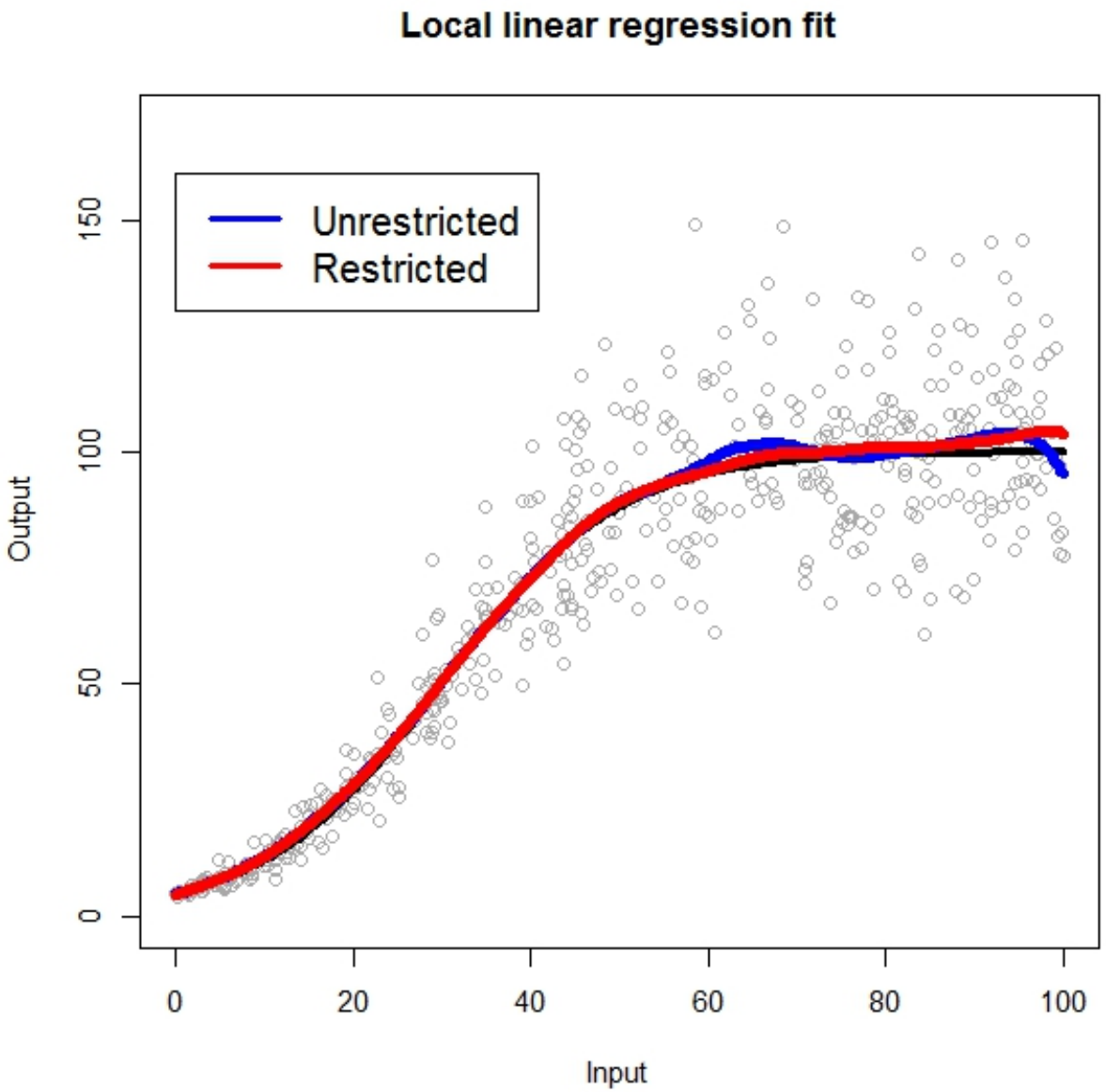


Local linear regression

General production model

$$lnY_i = g(\tilde{X}_i) + u_i, \text{ with i=1,...,n.} \tag{3}$$

Kernel weighting

- Continuous variables

$$l^c\left(\frac{X^c_{ik} - X^c_k}{\lambda^c_k}\right) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{X^c_{ik} - X^c_k}{\lambda^c_k}\right)^2} \tag{4}$$

- Categorical variables

$$l^u(X^u_{il}, X^u_l, \lambda^u_l) = \begin{cases} 1 - \lambda^u_l \text{ if } X^u_{il} = X^u_l, \\ \lambda^u_l/(c_l - 1) \text{ otherwise} \end{cases} \tag{5}$$

Local linear regression

Minimization problem

$$\min_{\{\alpha_0,\alpha_1\}} \sum_{i=1}^{n} (lnY_i - \alpha_0 - (X_i^c - X^c)\alpha_1)^2 \mathcal{K}_\gamma(\tilde{X}_i, \tilde{x}). \qquad (6)$$

, with $\mathcal{K}_\gamma(X_i, x) = W_{\lambda^c}(X_i^c, x^c) L_{\lambda^u}(X_i^u, x^u)$

, with $\gamma = (\lambda^c, \lambda^u)$.

Least squares cross-validation

$$CV(\gamma) = \frac{1}{n} \sum_{i=1}^{n} (lnY_i - \hat{g}_{-i}(\tilde{X}_i))^2 w(\tilde{X}_i) \qquad (7)$$

Nonparametric regression-based TFP estimation

Analogously to TFP estimation in Kumbhakar, Hesmati and Hjalmarsson (1999,SJE)

- TFP estimates are based on nonparametric estimates of technical change and output elasticities

$$\widehat{TFP}_t^{NP} = \frac{\partial g(\cdot)}{\partial t} + (RTS - 1) \sum_j \epsilon_j \frac{\dot{X}_j}{X_j}, \epsilon_j = \frac{\partial g(\cdot)}{\partial lnX_j}. \quad (8)$$

- Recall: Factor bias if $B_j = \frac{\partial^2 g}{\partial lnX_j \partial t} \neq 0$, for some j in $1, ..., m$.

- Main advantage: no parametric structure is imposed on the functional relationship between inputs and output

Imposing economic restrictions

Constrained nonparametric regression

- Parmeter, Sun, Henderson and Kumbhakar (2014, JPA)
- Linear estimator can be expressed as:

$$\hat{g}_j(\mathbf{x}) = \sum_{i=1}^{n} A_{j,i}(\tilde{X}) lnY_i. \tag{9}$$

- Weight $A_{0,i}(\tilde{X})$
- First order derivatives $A_{1,i}(\tilde{X})$ with respect to input lnX_1
- Imposing monotonicity: $A_{j,i}(\tilde{X}) = \frac{\partial A_{0,i}(\tilde{X})}{\partial lnX_j} \geq 0$, with $j = 1, ..., 4$.
- Constrained weighted bootstrapping

Data

- BELFIRST database provided by Bureau Van Dijk
- Database of income statements, balance sheets and social balance sheets
- Issue: specific issue or version of the database only contains information for the last ten years
- Therefore, we consulted different November issues of the database
- Data on the R&D activities (personnel) from the biennial OECD business R&D survey, covering the period 1996-2011, provided by the Belgian Science Policy Office.

Data

Representativeness of the raw data

# Firms in dataset	1220
# Firms as share of SBS	0.43
Coverage of firms with zero employment excl.	0.76
Coverage number of employees	0.71
Coverage of firms with all 'TFP' variables	0.17
Coverage of value added	0.74

Skill heterogeneity

	share of management	share of employees	share of workers	share of other
average 1997-2010	0.9	31.1	67.3	0.8
change 1997-2010	-0.4	6.8	-6.1	-0.2

Data

14 Manufacturing sectors included in the analysis

		Full	Balanced
10	Food products	6379	2055
13	Textiles	2470	585
16	Wood and of products of wood and cork; except furniture;articles of straw and plaiting mat.	1272	240
17	Paper and paper products	1268	495
18	Printing and reproduction of recorded media	2507	585
20	Chemicals and chemical products	2549	1200
22	Rubber and plastic products	2459	960
23	Other non-metallic mineral products	3026	1050
24	Basic metals	1763	735
25	Fabricated metal products, except machinery&equip.	6209	1710
26	Computer, electronic and optical products	1019	315
27	Electrical equipment	1155	420
28	Machinery and equipment n.e.c.	3217	960
31	Furniture	1686	555

Summary statistics

	Obs	Mean	St.Dev.	Med.
Defl. Turnover/10,000	36979	2479.30	6759.69	815.29
Workers in FTE	36979	59.65	115.29	27.00
Employees in FTE	36979	27.50	68.73	9.58
Defl. Capital/10,000	36979	403.82	1283.76	120.79
Defl. Materials/10,000	36979	1919.70	5776.54	558.88
Firm age	36979	24.97	18.08	20.00
$L_{FTE}^{R\&D} / L_{FTE}$	10693	0.05	0.10	0.02

Optimal bandwidth size

sector	Log LS	Log HS	Log C	Log M	t
10 Food	0.535	0.682	0.390	3.620	$3.410e^5$
13 Textiles	0.350	1.539	0.402	0.914	$3.686e^5$
16 Wood	0.650	0.863	0.223	$4.853e^4$	3.430
17 Paper	0.462	0.375	0.614	0.592	1.379
18 Printing	0.570	0.298	0.356	0.811	13.701
20 Chemicals	0.530	0.403	0.331	0.338	48.143
22 Rubber-Plastic	1.226	0.405	0.308	2.065	4.527
23 Non-metallic mineral.	0.346	0.526	0.414	$4.841e^5$	4.121
24 Basic metals	0.480	0.595	0.583	0.844	13.600
25 Fabricated metal prod.	0.552	0.469	0.484	2.065	5.721
26 Computer, elec.& opt.	0.907	0.133	1.593	0.479	2.598
27 Electrical equipment	0.855	0.844	0.468	0.638	1.002
28 Mach.&Equipm.	0.166	0.585	0.997	1.970	3.842
31 Furniture	0.667	0.967	0.243	1.267	2.801

Factor-biased technical change: 1996-2010

Nace	$\Delta\epsilon_{LS}$	$\Delta\epsilon_{HS}$	$\Delta\epsilon_{M}$	$\Delta\epsilon_{C}$
10 Food	0	0	0	0
13 Textiles	0*	0	0	0
16 Wood	-0.03	0.02	0.02	0.01
17 Paper	-0.12*	-0.06	0	0.15*
18 Printing	-0.02*	0.01	0.01*	0
20 Chemicals	0	0	0	0
22 Rubber-Plastic	-0.05*	0.04	0.05	-0.03
23 Non-metallic mineral.	-0.08*	0.08*	-0.02	0.02*
24 Basic metals	0	0	0	0
25 Fabricated metal prod.	-0.02	-0.01	0.05*	0
26 Computer, elec.& opt.	-0.07	-0.09	-0.81*	0.6
27 Electrical equipment	-0.04	-0.03	0.03	-0.04*
28 Mach.&Equipm.	-0.15*	0	0.02	0
31 Furniture	-0.05	-0.01	0.14*	-0.02

Factor-biased technical change: 1996-2007

Nace	$\Delta\epsilon_{LS}$	$\Delta\epsilon_{HS}$	$\Delta\epsilon_{M}$	$\Delta\epsilon_{C}$
10 Food	0	0	0	0
13 Textiles	0*	0	0	0
16 Wood	0	0.02	0.05	0
17 Paper	-0.03	-0.02	-0.02	0
18 Printing	-0.01*	0.01	0.01*	0
20 Chemicals	0	0	0	0
22 Rubber-Plastic	-0.03*	0.04	0.03	-0.02
23 Non-metallic mineral	-0.06*	0.07*	-0.03	0.02*
24 Basic metals	0	0	0	0
25 Fabricated metal prod.	-0.02	0	0.04*	0
26 Computer, elec.& opt.	-0.1	-0.08	-0.81*	0.9*
27 Electrical equipment	-0.05	-0.08	0.08	-0.04*
28 Mach.&Equipm.	-0.1*	-0.01	0.01	-0.01
31 Furniture	0.01	-0.02	0.05	-0.03*

Factor-biased technical change: balanced sample

Nace	$\Delta\epsilon_{LS}$	$\Delta\epsilon_{HS}$	$\Delta\epsilon_{M}$	$\Delta\epsilon_{C}$
	1996-2010			
10 Food	0	0.01	-0.02	0
20 Chemicals	-0.09*	-0.12*	0.09*	0.01
22 Rubber-Plastic	0.01	-0.11	0.02	0.05*
23 Non-metallic mineral	-0.17*	-0.03	0	-0.07
24 Basic metals	-0.1	0.03	0.05	-0.07
25 Fabricated metal prod.	-0.09*	-0.02	0.06	0
28 Mach.&Equipm.	0.11	0.05	0.13	0
	1996-2007			
10 Food	0	0.01	-0.02	0
20 Chemicals	-0.1*	-0.12*	0.08*	0.02
22 Rubber-Plastic	0.02	-0.14*	-0.01	0.05*
23 Non-metallic mineral	-0.15*	-0.05	-0.03	-0.06
24 Basic metals	-0.01	-0.03	0.04	-0.06
25 Fabricated metal prod.	-0.06*	-0.02	0.04	0
28 Mach.&Equipm.	0.1	0.06	0.14	-0.01

Allowing for heterogeneity in technology

Detailed analysis of sector 25

- Fabricated metal products, except machinery and equipment
- Overall we find a bias in favour of materials and against low-skilled labour
- Control for R&D and firm age

Allowing for heterogeneity in technology

	Full sample		
	1996-2010	1996-2007	2007-2010
$\Delta\epsilon_{LS}$	-0.02	-0.02	-0.01*
$\Delta\epsilon_{HS}$	-0.01	0	0
$\Delta\epsilon_{M}$	0.05*	0.04*	0.01*
$\Delta\epsilon_{C}$	0	0	0

	Balanced sample		
	1996-2007	2007-2010	1996-2010
$\Delta\epsilon_{LS}$	-0.09*	-0.06*	-0.03*
$\Delta\epsilon_{HS}$	-0.02	-0.02	0
$\Delta\epsilon_{M}$	0.06	0.04	0.02
$\Delta\epsilon_{C}$	0	0	0

Allowing for heterogeneity in technology

	High R&D		
	1996-2010	1996-2007	2007-2010
$\Delta\epsilon_{LS}$	-0.04*	-0.03*	0
$\Delta\epsilon_{HS}$	0.01	0.01	0
$\Delta\epsilon_{M}$	0.01	0.01	0
$\Delta\epsilon_{C}$	0	0	0

	High R&D - Balanced		
	1996-2010	1996-2007	2007-2010
$\Delta\epsilon_{LS}$	-0.03	-0.01	-0.02
$\Delta\epsilon_{HS}$	-0.04	-0.03	-0.01
$\Delta\epsilon_{M}$	0.15*	0.11*	0.04*
$\Delta\epsilon_{C}$	0.02	0.02*	0

Allowing for heterogeneity in technology

	Young firms		
	1996-2010	1996-2007	2007-2010
$\Delta\epsilon_{LS}$	-0.01	-0.01	0
$\Delta\epsilon_{HS}$	-0.01	-0.01	0
$\Delta\epsilon_{M}$	0.03*	0.02*	0.01*
$\Delta\epsilon_{C}$	0.01*	0.01*	0*

	Mature firms		
	1996-2010	1996-2007	2007-2010
$\Delta\epsilon_{LS}$	-0.09*	-0.06*	-0.03*
$\Delta\epsilon_{HS}$	-0.02	-0.02	0
$\Delta\epsilon_{M}$	0.06	0.04	0.02
$\Delta\epsilon_{C}$	0	0	0

	Old firms		
	1996-2010	1996-2007	2007-2010
$\Delta\epsilon_{LS}$	-0.02	-0.01	0
$\Delta\epsilon_{HS}$	-0.01	-0.01	0
$\Delta\epsilon_{M}$	0.03*	0.02*	0.01*
$\Delta\epsilon_{C}$	0.01*	0.01*	0*

Implications for TFP analysis

Comparison with

- Semiparametric Hicks-neutral Technical Change estimates
- Hicks-neutral parametric translog model
- TT1 Translog model
- TT3 Translog model

Overall

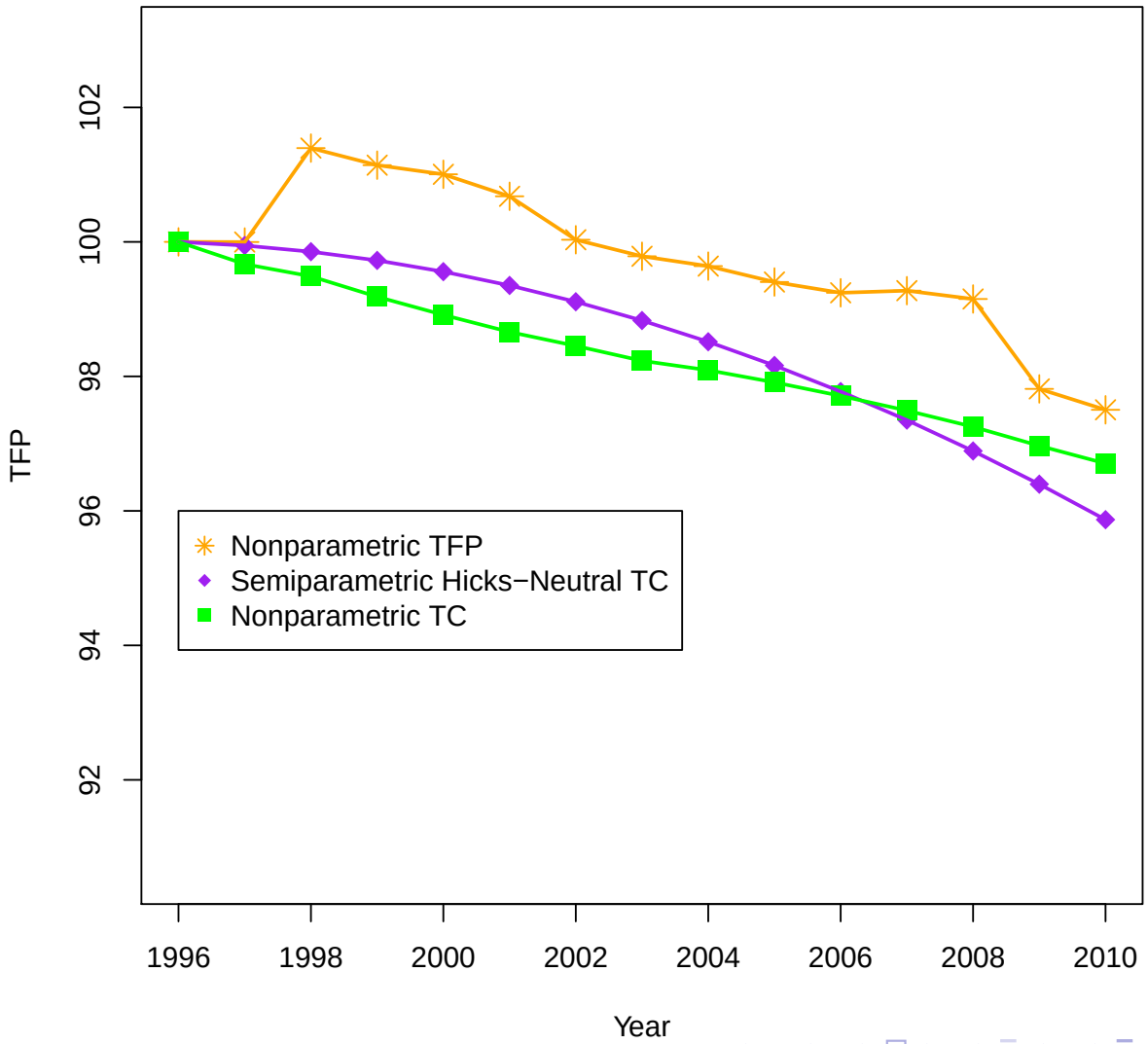
- Slow TFP growth
- Functional form specification, including Hicks neutrality, considerably impacts TFP change estimates
- Nonparametric estimates are rather conservative
- TT3 Translog estimates are unstable

In sum

- Advisable to at least test for Hicks neutrality prior to TFP analysis

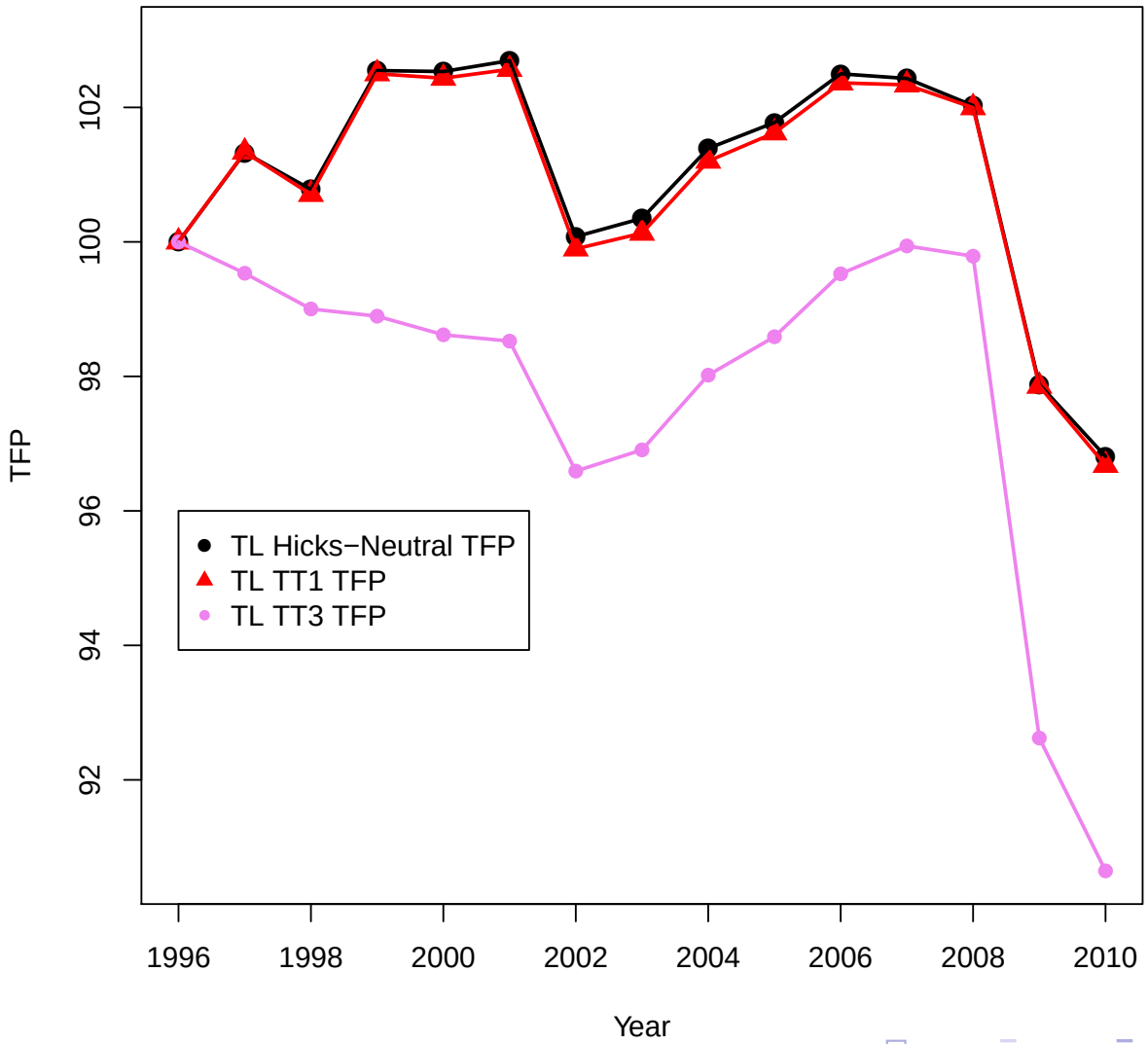
Implications for TFP analysis

Sector 23: Other non-metallic mineral products



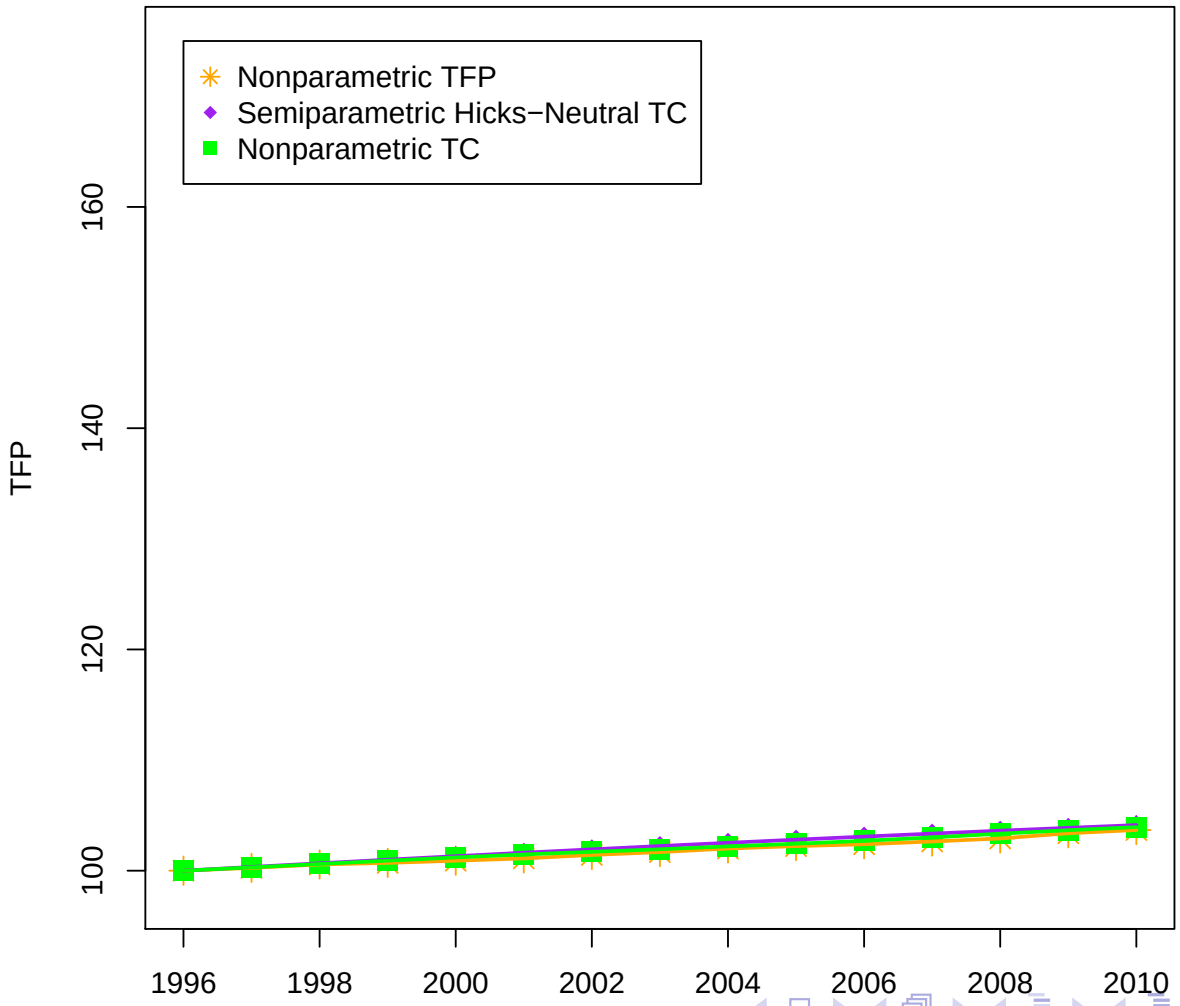
Implications for TFP analysis

Sector 23: Other non-metallic mineral products



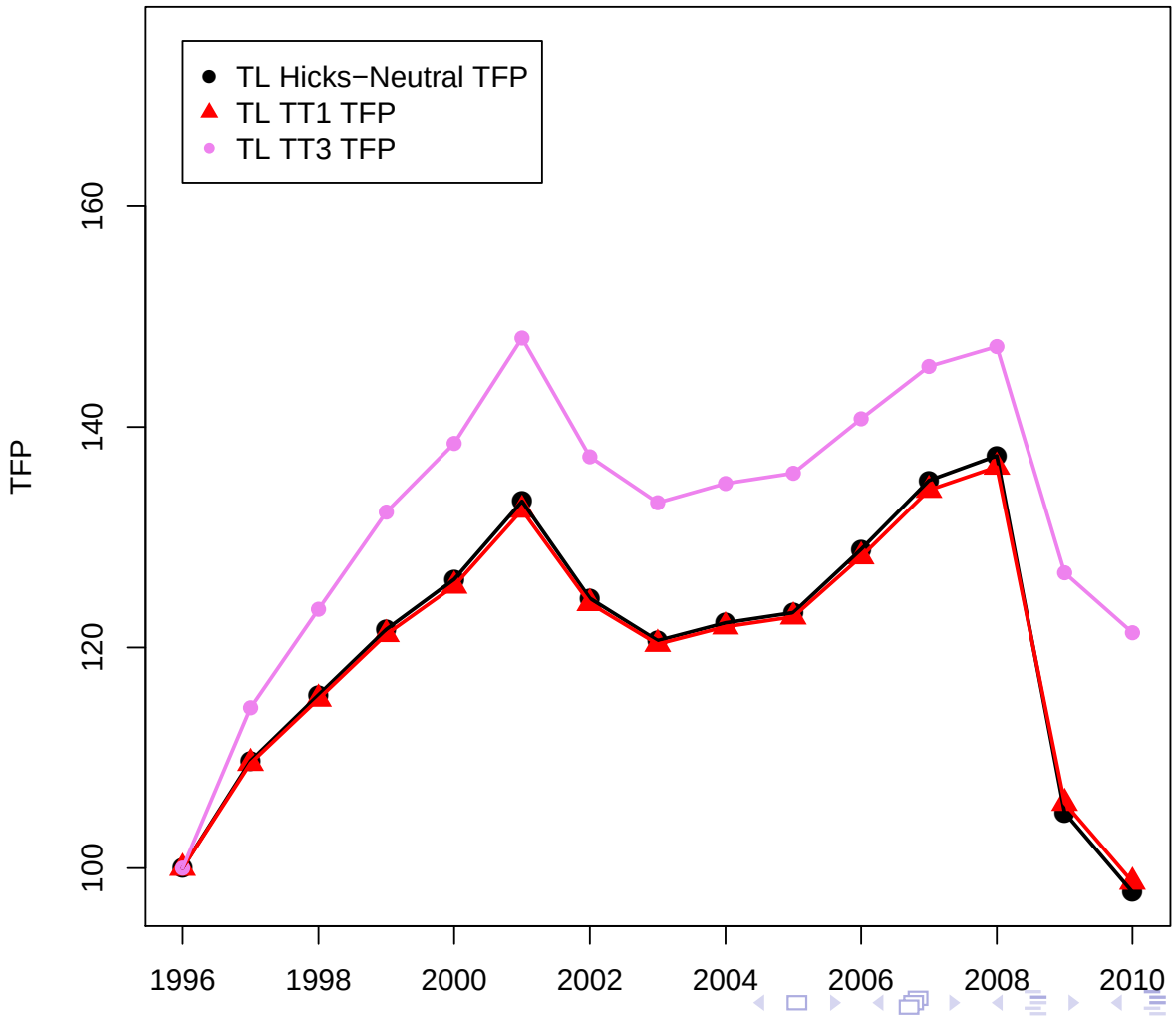
Implications for TFP analysis

Sector 25: Fabricated metal products, except machinery and equipment



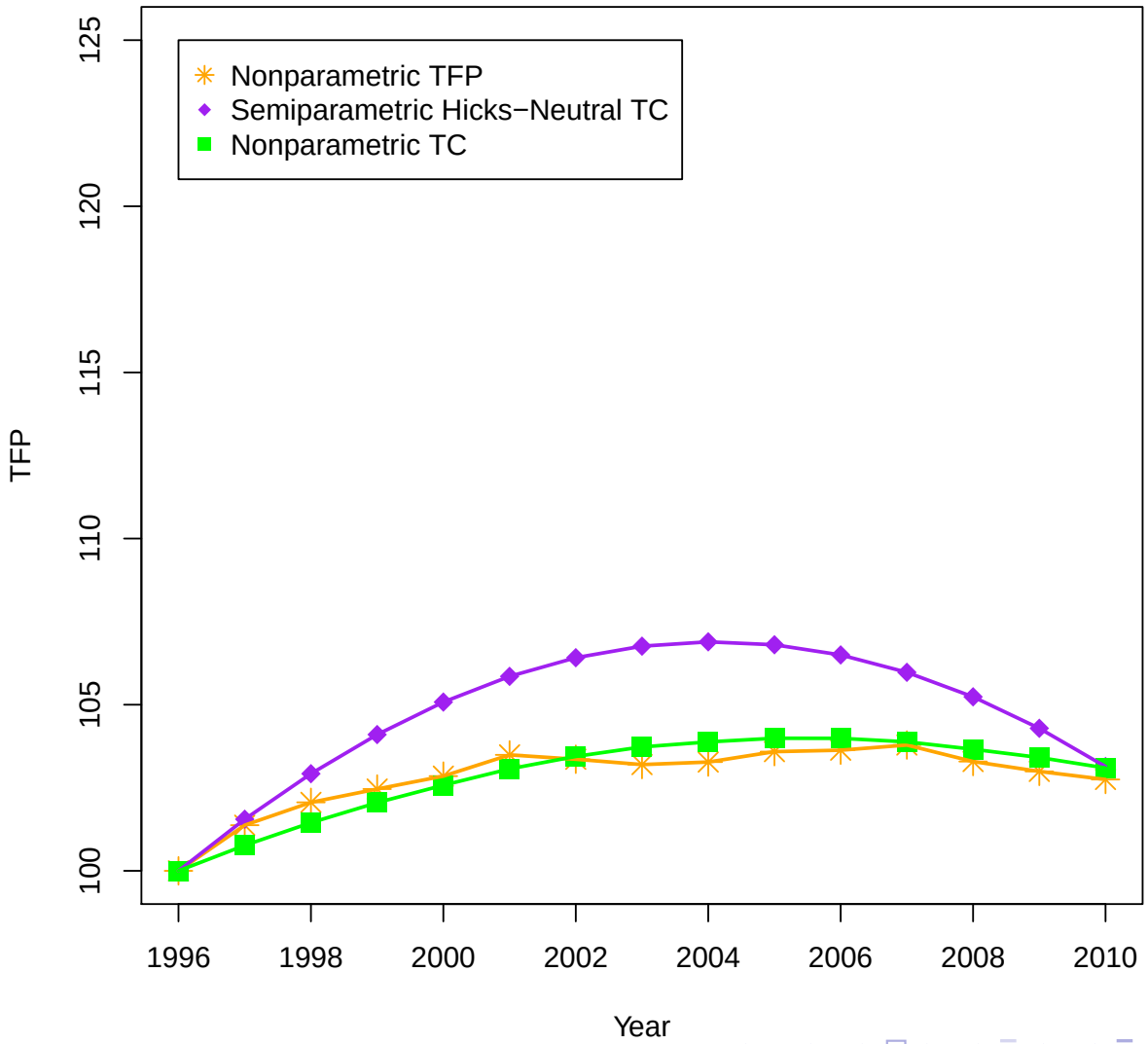
Implications for TFP analysis

Sector 25: Fabricated metal products, except machinery and equipment



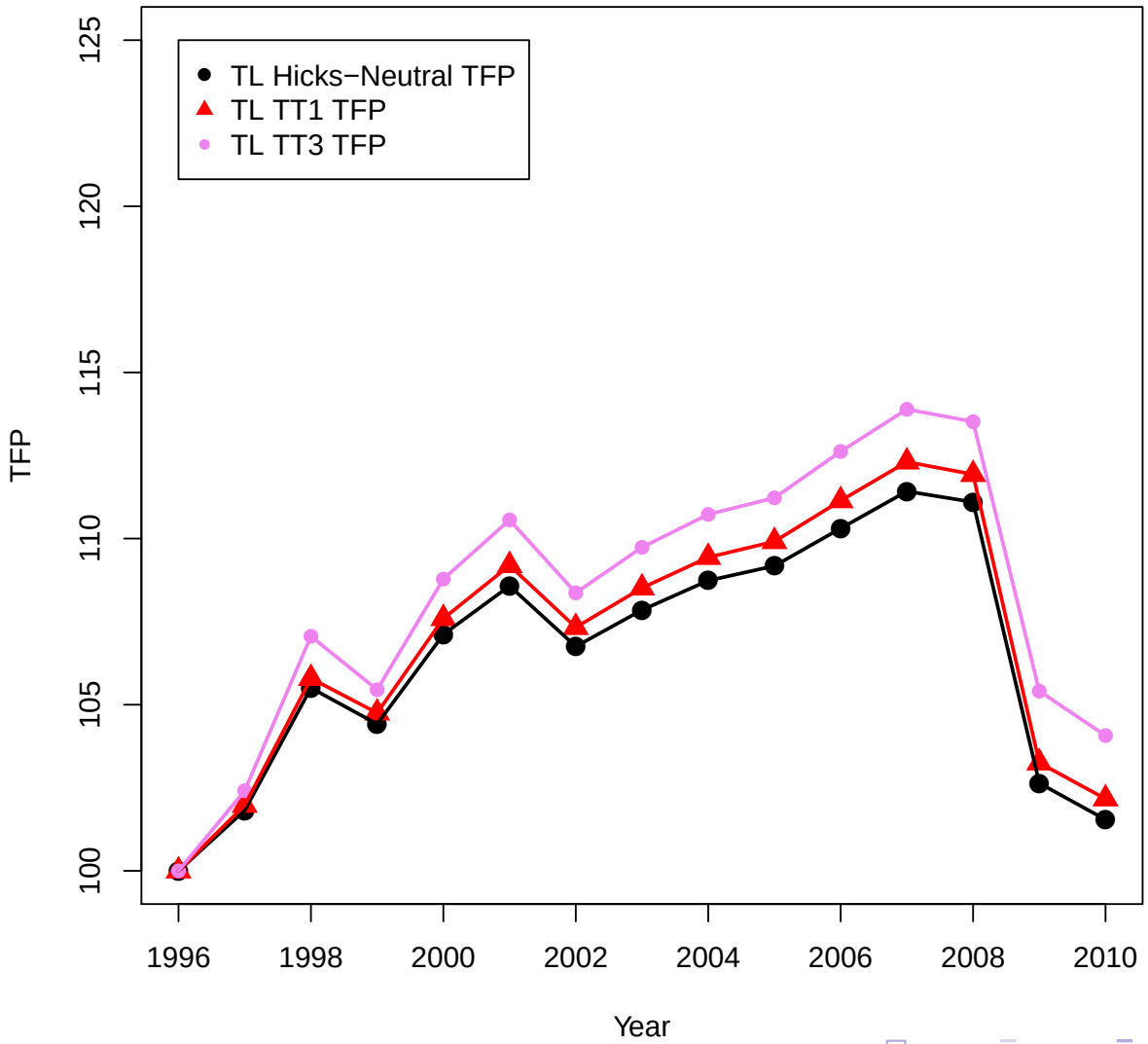
Implications for TFP analysis

Sector 28: Machinery and equipment n.e.c.



Implications for TFP analysis

Sector 28: Machinery and equipment n.e.c.



Concluding remarks

- Vast literature on TFP estimation at the firm level makes the explicit assumption of Hicks neutrality
- We test for factor biases in manufacturing sectors with distinct characteristics without imposing a parametric specification of the production function
- We use firm-level BELFIRST data covering 1996-2010 and firm-level R&D data from Belspo

Concluding remarks

- We reject Hicks neutrality in a significant proportion of sectors
- We show that technical change that is low-skilled labour-saving and materials-using is widespread
- We show this also occurs 'within-firm' and is not sensitive for allowing for heterogeneity in technology
- Advisable to at least test for Hicks neutrality prior to TFP analysis
- Further research: micro-drivers of factor biases