Evolution in Markets

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1. **Innovation and Selection/Competition are at the core of evolutionary approaches to markets/industries**
2. **Formally, extended versions of the replicator dynamics framework allow understanding the dynamic patterns of markets**
3. **Empirically, the validation of the theoretically derived pattern on the one hand but also of the general working of replicator dynamics is difficult and works „occasionally"**
4. **The low empirical evidence challenges the replicator concept**

Part I

Markets

- **Markets are core to understanding economics**
  - Markets are considered to coordinate demand and supply
  - Markets are considered to organize competition
- **Major supply side dimensions of market**
  - Competition of firms
  - Innovation as major influence on competitiveness
- **Market dynamics**
  - The way demand and supply is coordinated over time (e.g. Cobb-web)
  - The way competition between firms develops over time
- **Market evolution**
  - The way innovation activities and market competition interact and shape the development of markets/industries (industrial dynamics, ILC, …)

- **“Romantic Ideas” on Innovation**
  - innovative activities and the process of creative destruction (Schumpeter 1942) is based on a selection dynamics, implying that within a group of heterogeneous firms:
    - firms with innovative performance above average grow - or enter the market
    - firms with innovative performance below average shrink – eventually exit the market

- **Neo-Schumpeterian tradition (industrial dynamics)**
  - Based on Nelson/Winter (1982), ... Fagiolo/Dosi (2003)
  - micro behavior ➔ industry outcomes ➔ micro behavior ➔ industry outcomes
  - dynamic forces: (1) technological competition and selection, (2) innovation
  - formal models: use of replicator (or Lotka-Volterra) equations (Metcalfe 1994)

- **Mainstream based heterogeneity models**
  - Jovanovic (1982), ... Aghion et al. (2005)
  - market competition: assumptions on the type of market, no dynamics
  - innovativeness is given by a stochastic process often combined with learning (imitation)
  - no connection between innovation, competition and reallocation

- **Industry Life Cycle models**
  - Klepper (1996)
  - endogenous determination of the conditions for entry and exit as well as for performance

Part II

Theory of Markets as a locus of innovative change and competition

1. Selection dynamics
2. Selection and innovation dynamics
3. Selection, innovation and cooperation dynamics

- **Cantner U., Heterogenität, Technologischer Fortschritt und Spillover-Effekte, in: M. Lehmann-Waffenschmidt, Studien zur Evolutorischen Ökonomik V, Berlin: Duncker&Humblodt, 2002, 15-40**

- **Cantner U., Competition in innovation, in: U. Cantner, A. Greiner, T. Kuhn and A. Pyka (eds), Futurity and Economics, Edward Elgar: Cheltenham, 2009, 13-33.**

- **Cantner U., Evolution in Markets, mimeo, forthcoming in Pianta (2015), Proceedings of the LINCEI Conference, Roem Now. 2014**

- **Market competition via replicator dynamics**

$$\dot{s}_i = s_i \cdot \lambda \cdot \left(f_i - \bar{f}\right) \qquad \forall\, i = 1, \dots, n \quad \bar{f} = \sum_j s_j f_j$$

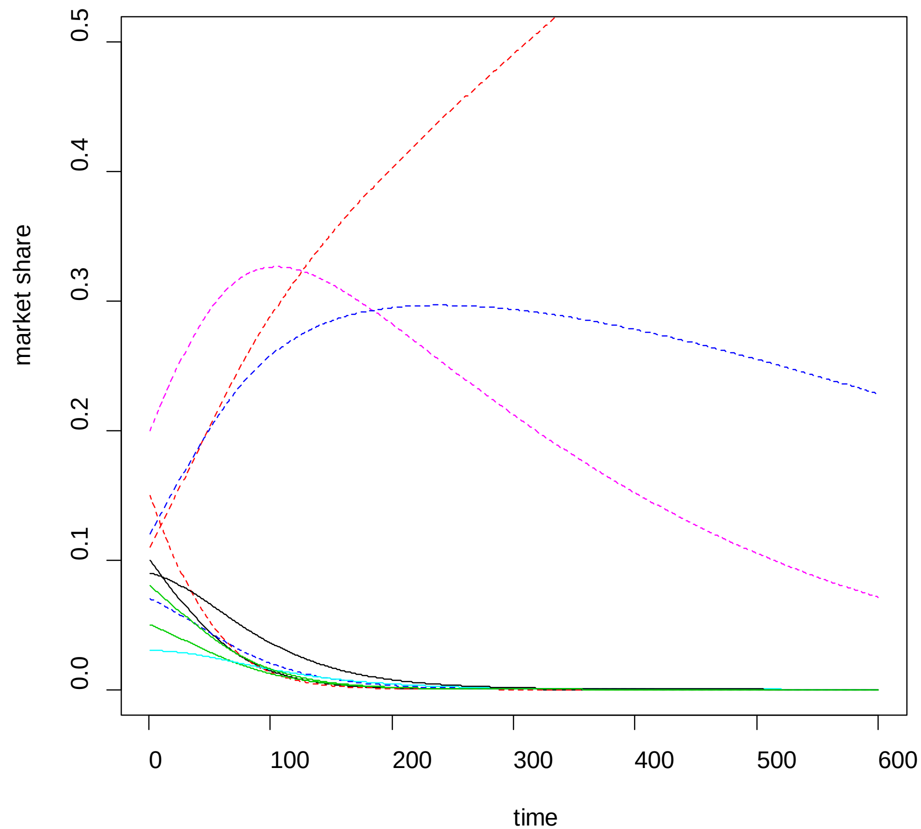
  - Firms / products indexed $i, i = 1, \dots, n$
  - Market share $s_i \geq 0 \quad \sum s_i = 1$
  - Change of market share of firm i over time $\dot{s}_i$
  - Fitness: unit costs, productivity, … f_i
  - Speed of market selection $\lambda > 0$
  - In general all variables time indexed

- **Dynamics depends on** $\left(f_i - \bar{f}\right)$
  - $\left(f_i - \bar{f}\right) > 0 \;\rightarrow \dot{s}_i < 0$
  - $\left(f_i - \bar{f}\right) < 0 \;\rightarrow \dot{s}_i < 0$

- **Dynamics of** $\bar{f}$**:** $\dot{\bar{f}} \sim \sigma^2(f_i)$

- **Market competition** $\dot{s}_i = s_i \cdot \lambda \cdot (f_i - \bar{f}) \quad \forall\, i = 1, \ldots, n \quad \bar{f} = \sum_j s_j f_j$
  - Replicator dynamics

- **Reducing initial heterogeneity**
  - Market clearing
  - Differential profit
  - Differential (dis)investment



$\lambda = 0.04$

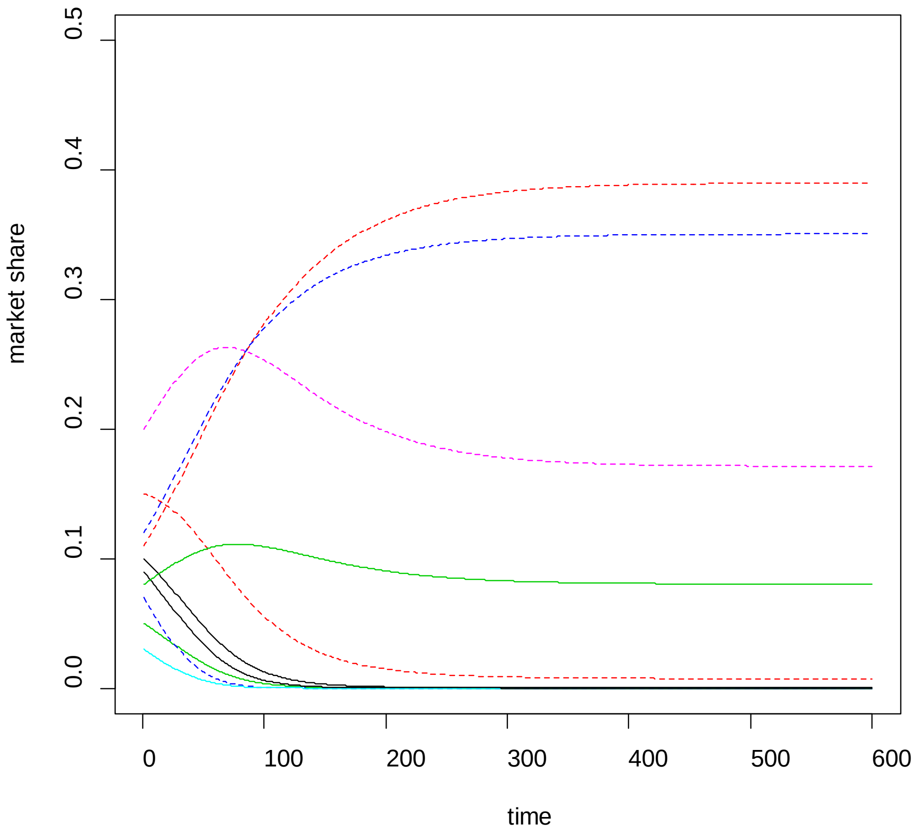
- **Market competition** $\dot{s}_i = s_i \cdot \lambda \cdot (f_i - \bar{f}) \quad \forall\, i = 1, \dots, n \quad \bar{f} = \sum_j s_j f_j$
- **Differential endogenous dynamics of heterogeneity**
- **Innovation** $\boldsymbol{\dot{f}_i = \gamma \cdot g(s_i)} \qquad [\rightarrow f_{max}]$
  - Case 1 - constant dynamic returns to scale: $\partial \dot{f}_i / \partial s_i = 0 \quad \forall\, i = 1, \dots, n$
  - Case 2 - increasing dynamic returns to scale: $\partial \dot{f}_i / \partial s_i > 0 \quad \forall\, i = 1, \dots, n$
  - Case 3 - decreasing dynamic returns to scale: $\partial \dot{f}_i / \partial s_i < 0 \quad \forall\, i = 1, \dots, n$

Case 1

constant dynamic returns to scale:

$$\partial \dot{f}_i / \partial s_i = 0 \quad \forall\, i = 1, \ldots, n$$

Resulting pattern dependent on the relation between innovation dynamics γ and selection / competition dynamics λ



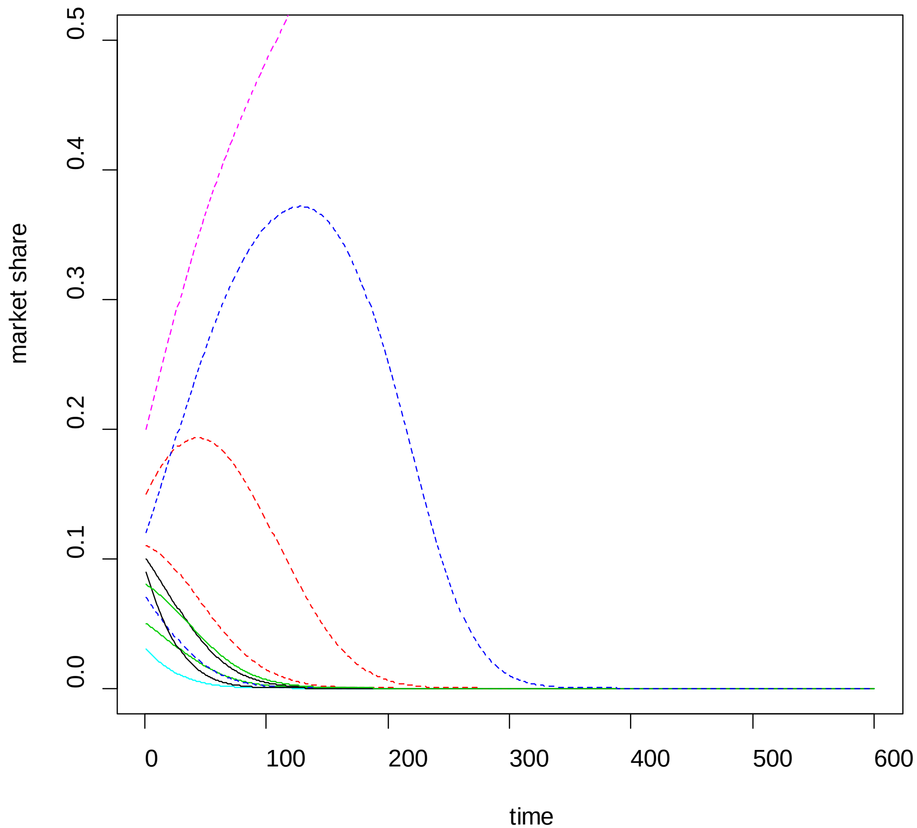
$\lambda = 0.04, \gamma = 0.005$

Case 2

increasing dynamic returns to scale:

$$\partial \dot{f}_i / \partial s_i > 0 \quad \forall\, i = 1, \ldots, n$$

Resulting pattern dependent on the relation between $\boldsymbol{\gamma}$ and $\boldsymbol{\lambda}$



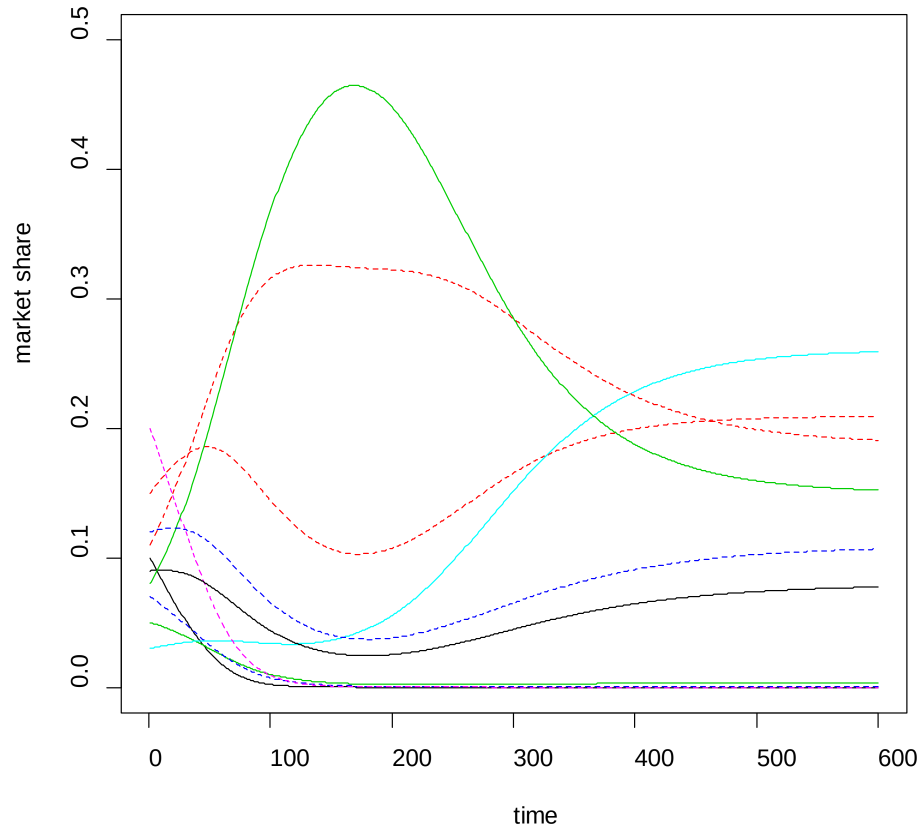
$\lambda = 0.06, \gamma = 0.005$

Case 3

decreasing dynamic returns to scale:

$$\partial \dot{f}_i / \partial s_i < 0 \quad \forall\, i = 1, \ldots, n$$

Resulting pattern dependent on the relation between $\boldsymbol{\gamma}$ and $\boldsymbol{\lambda}$



$\lambda = 0.06,\ \gamma = 0.005$

- **Market competition**

  $\dot{s}_i = s_i \cdot \lambda \cdot \left(f_i - \bar{f}\right) \quad \forall\, i = 1, \dots, n \quad \bar{f} = \sum_j s_j f_j$

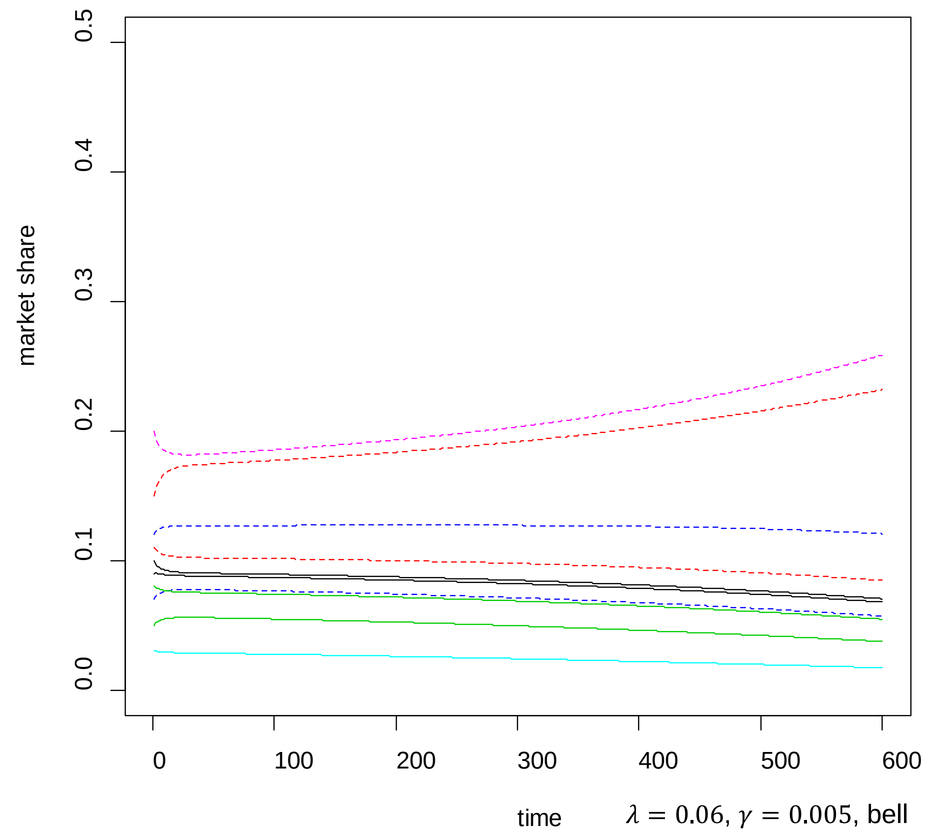
- **Innovation**

  $\dot{f}_i = \gamma \cdot g(s_i, z_i) \qquad [\to f_{max}]$

- **Another type of interaction**

- **Spillovers / Cooperation**

  $\boldsymbol{z_i = h\left(\max(f_j) - f_i\right)}$



Part III

Empirics of Markets as a locus of innovative change and competition

1. Empirical approaches – an overview
2. Indirect measurement
3. Aggregate performance and its decomposition
4. Direct measurement

1. Empirical Approaches - overview

– Indirect approaches

- Coad (2007): balanced panel (France 1996-2004), profit rate as fitness, growth rates
- Bottazzi et al (2002, 2008): (Italy manufacturing 1998-2003), labor productivity, profitability as fitness, growth rates
- Cantner et al. (2009): ILC empirics, innovation related determinants of survival

– Aggregate performance and its decomposition

- Baldwin & Gu (2003): for Canadian manufacturing; Disney et al. (2003): for UK manufacturing
- Metcalfe & Ramoglan (2007): decomposition of labor productivity and unit labor requirement
- Cantner & Krüger (2008): for German manufacturing
- Dosi et al (2015): comparing industries of various countries

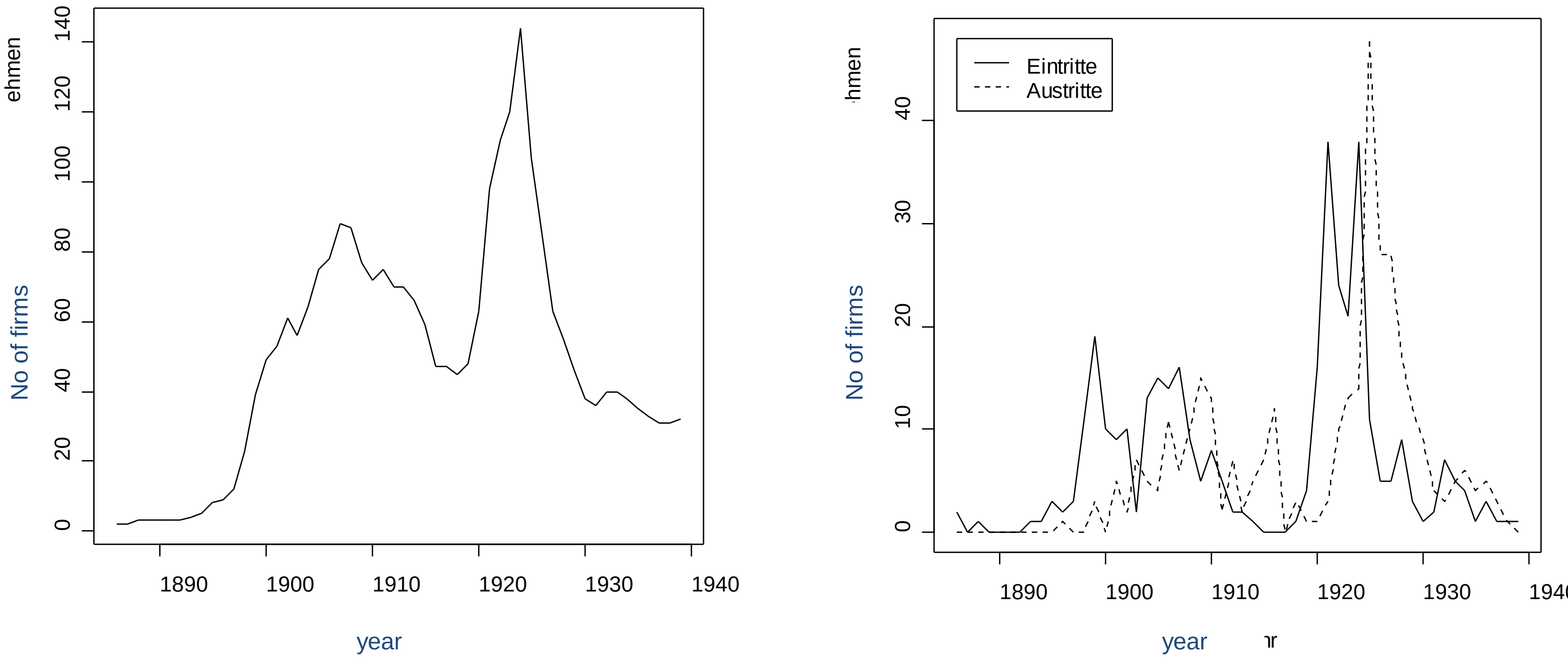
– Direct approaches

- Metcalfe & Calderini (2000): unbalanced panel (Italy, steel, 1988-1996), unit costs as fitness, market share change, selection coefficient
- Cantner , Krüger & Söllner (2011): product level, market instead of industry demarcation, quality-price ratio as fitness criterion

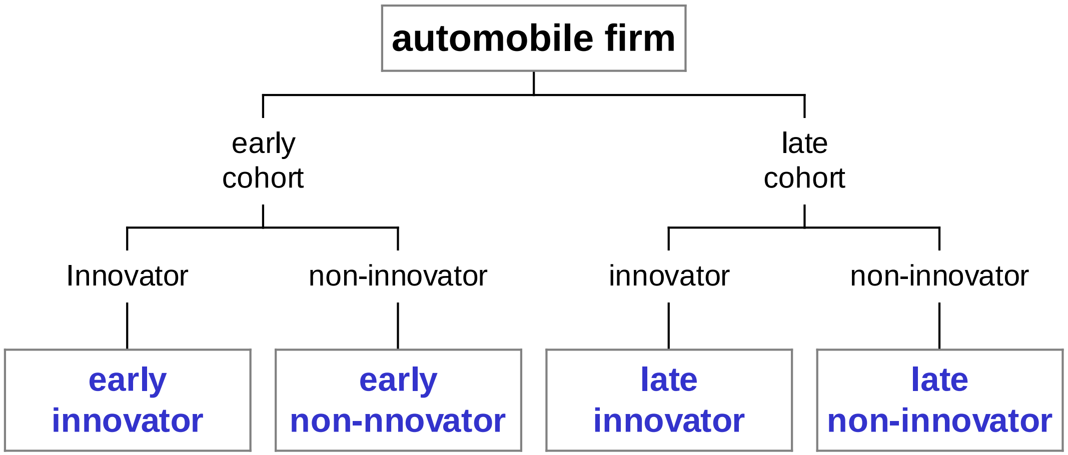
2. Indirect approaches

- **Cantner, U., J. Krüger, K. v. Rhein, Knowledge Compensation in the German Automobile Industry, Applied Economics 43(22), 2011, 2941-2951**

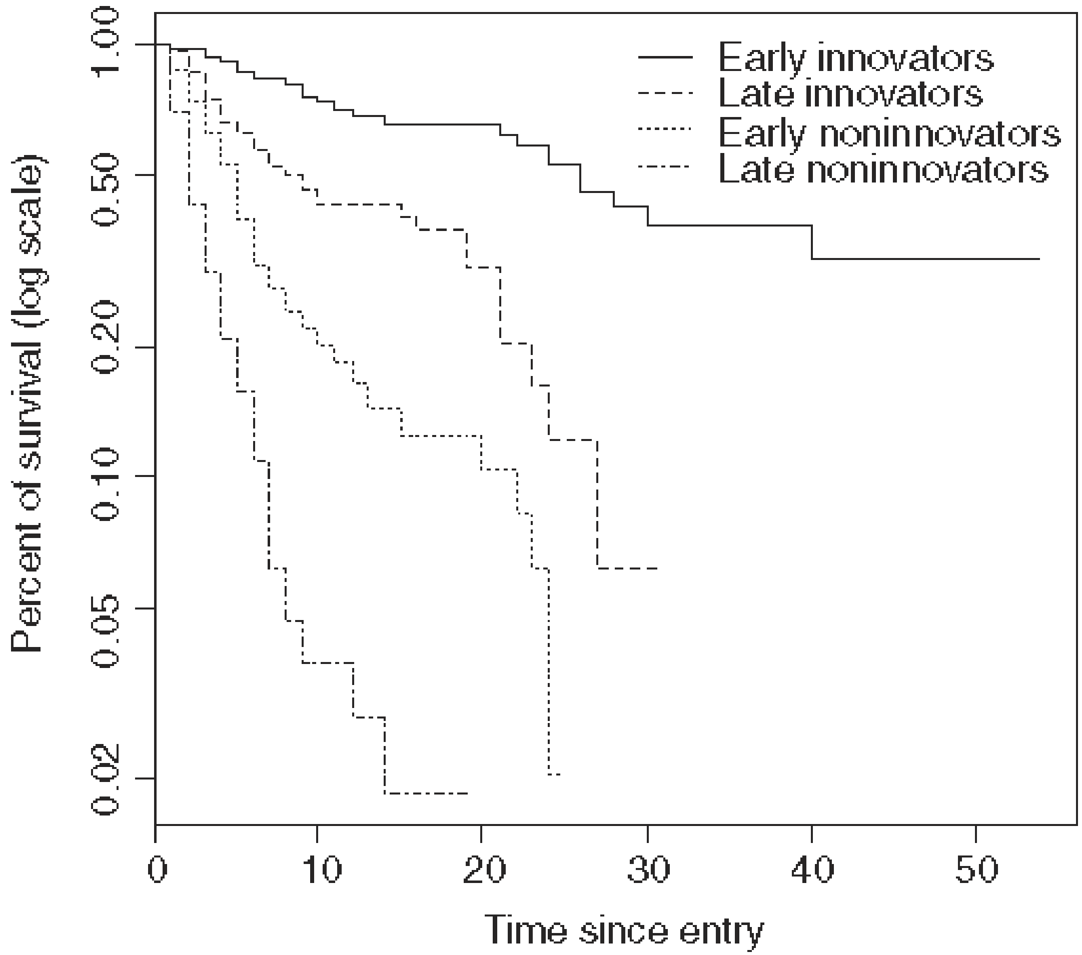
German automobiles



(Source: Cantner/Dreßler 2003)



Category	Periode	# firms	variable
cohort 1	1886-1901	56	**E1**
cohort 2	1902-1906	52	**E2**
cohort 3	1907-1922	126	**E3**
cohort 4	1923-1939	115	**E4**



Early innovators
Late innovators
Early noninnovators
Late noninnovators
Percent of survival (log scale)
1.00
0.50
0.20
0.10
0.05
0.02
0
10
20
30
40
50
Time since entry

	(A)	(B)	(C)
Dep. variable: **exit hazard**	cohorts 1 vs. 2-4	cohorts 1-2 vs. 3-4	cohorts 1-3 vs. 4
early innovators	-2,224***	-1,956***	-2,170***
	(0,002)	(0,001)	(0,000)
late innovators	-2,197***	-1,588***	-1,547***
	(0,000)	(0,000)	(0,004)
late non- innovators	0,333	0,739***	0,760***
	(0,399)	(0,008)	(0,000)
R^2	0,206	0,250	0,264
n	333	333	333

Notes: Robust standard are reported errors in parentheses. ***1%, **5%, and *10% level of significance

- **Core results**
  - Differential fitness in terms of innovativeness and in terms of accumulated experience show effect on survival
  - Exit dimension of replicator dynamics is taken into account
  - Market share dynamics not explicit
    - What kind of exit?
  - Very indirect test of replicator dynamics to work

3. Aggregate performance and its decomposition

- **Cantner U., J. Krüger, Micro-Heterogeneity and Aggregate Productivity Development in the German Manufacturing Sector - Results from a Decomposition Exercise, Journal of Evolutionary Economics 18(2), 2008, 119-134**

- **Decomposition of the smooth development at the aggregate level into different underlying dynamics**
  - Productivity development at the industry level decomposed into firm level dynamics
  - Market competition $\dot{s}_i = s_i \cdot \lambda\left(f_i - \bar{f}\right) \quad \forall\, i = 1, \dots, n \quad \bar{f} = \sum_j s_j f_j$
  - Innovation $\dot{f}_i = \lambda \cdot g(s_i) \qquad [\rightarrow f_{max}]$
  - Aggregate Dynamics $\dot{\bar{\boldsymbol{f}}} = \sum_{\boldsymbol{j}}\left(\dot{\boldsymbol{f}}_{\boldsymbol{j}} \boldsymbol{s}_{\boldsymbol{j}} + \dot{\boldsymbol{s}}_{\boldsymbol{j}} \boldsymbol{f}_{\boldsymbol{j}}\right)$ within effect and between effect

- **Decomposition (Foster et al. 1998)**
  - Three groups of firms
    - C: persistent firms N: entering firms X: exiting firms
  - Average productivity in t $\bar{a}_t^s = \sum_i s_{it} a_{it}$
  - Average productivity in $t-k$ $\bar{a}_{t-k}^s = \sum_i s_{it-k} a_{it-k}$
  - Change in the average productivity between $t-k$ and t $\Delta\bar{a}_t^s = \bar{a}_t^s - \bar{a}_{t-k}^s = \sum_{i\in C\cup N} s_{it} a_{it} - \sum_{i\in C\cup X} s_{it-k} a_{it-k}$

$$\Delta\bar{a}_t^s = \sum_{i\in C} s_{it-k}\Delta a_{it} + \sum_{i\in C} \Delta s_{it}(a_{it-k} - \bar{a}_{t-k}^s) + \sum_{i\in C} \Delta s_{it}\Delta a_{it} + \sum_{i\in N} s_{it}(a_{it} - \bar{a}_{t-k}^s) - \sum_{i\in X} s_{it-k}(a_{it-k} - \bar{a}_{t-k}^s)$$

within between covariance entry exit

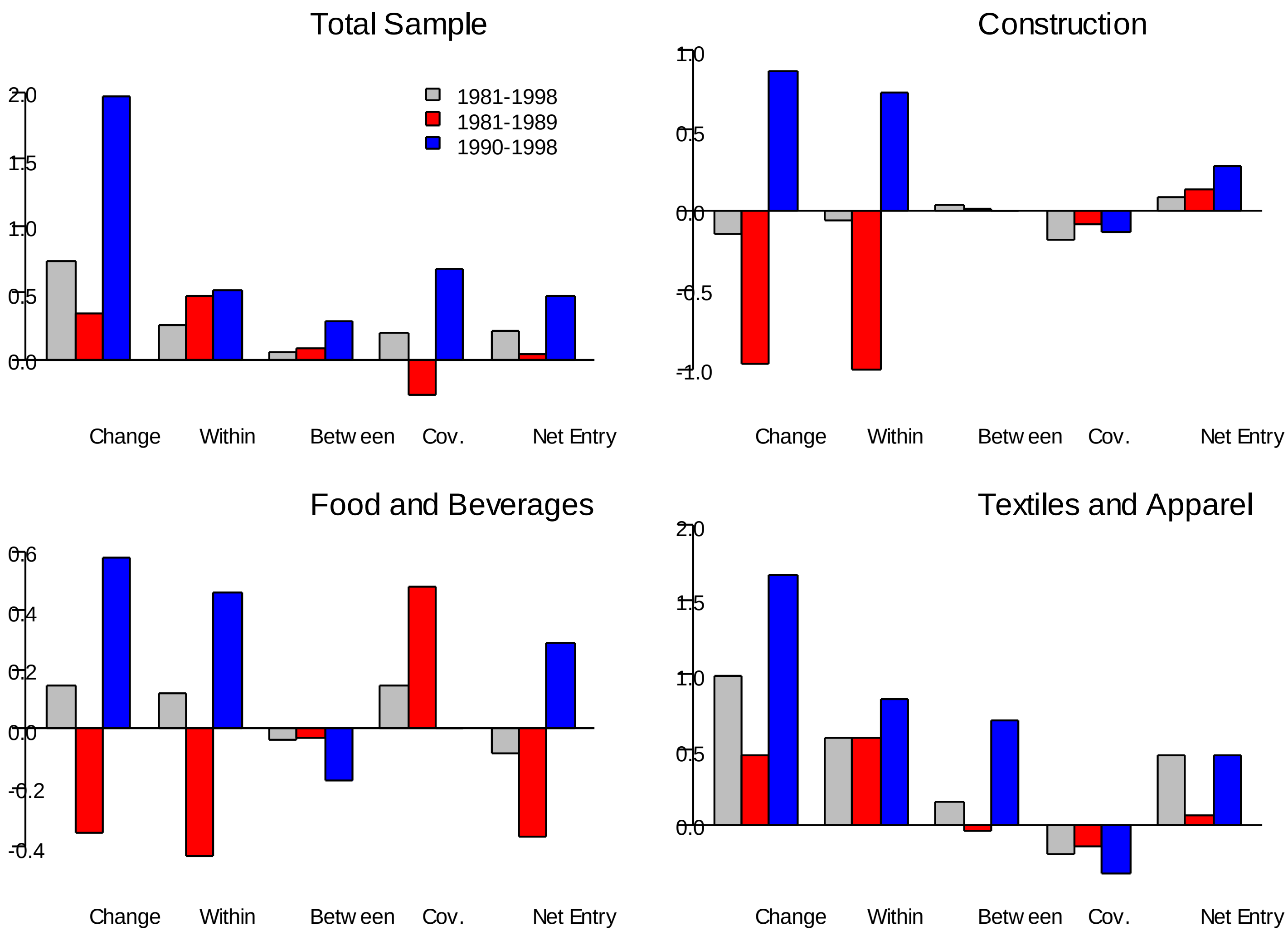
Table 1
Industry Composition of the Sample 1981-1998

Industry	SIC2	Shortcut	Min. # Firms	Max. # Firms
Construction	15, 16, 17	Construction	22	49
Food and Beverages	20, 21	Food	53	87
Textiles and Apparel	22, 23	Textiles	26	48
Paper and Printing	26, 27	Paper	13	32
Chemicals and Petroleum	28, 29	Chemicals	50	107
Rubber and Plastics	30	Rubber	12	23
Metal Products	33, 34	Metal	45	91
Machinery and Equipment	35	Machinery	75	150
Electronics	36	Electronics	31	66
Transportation Equipment	37	Transportation	18	50
Instruments	38	Instruments	14	23

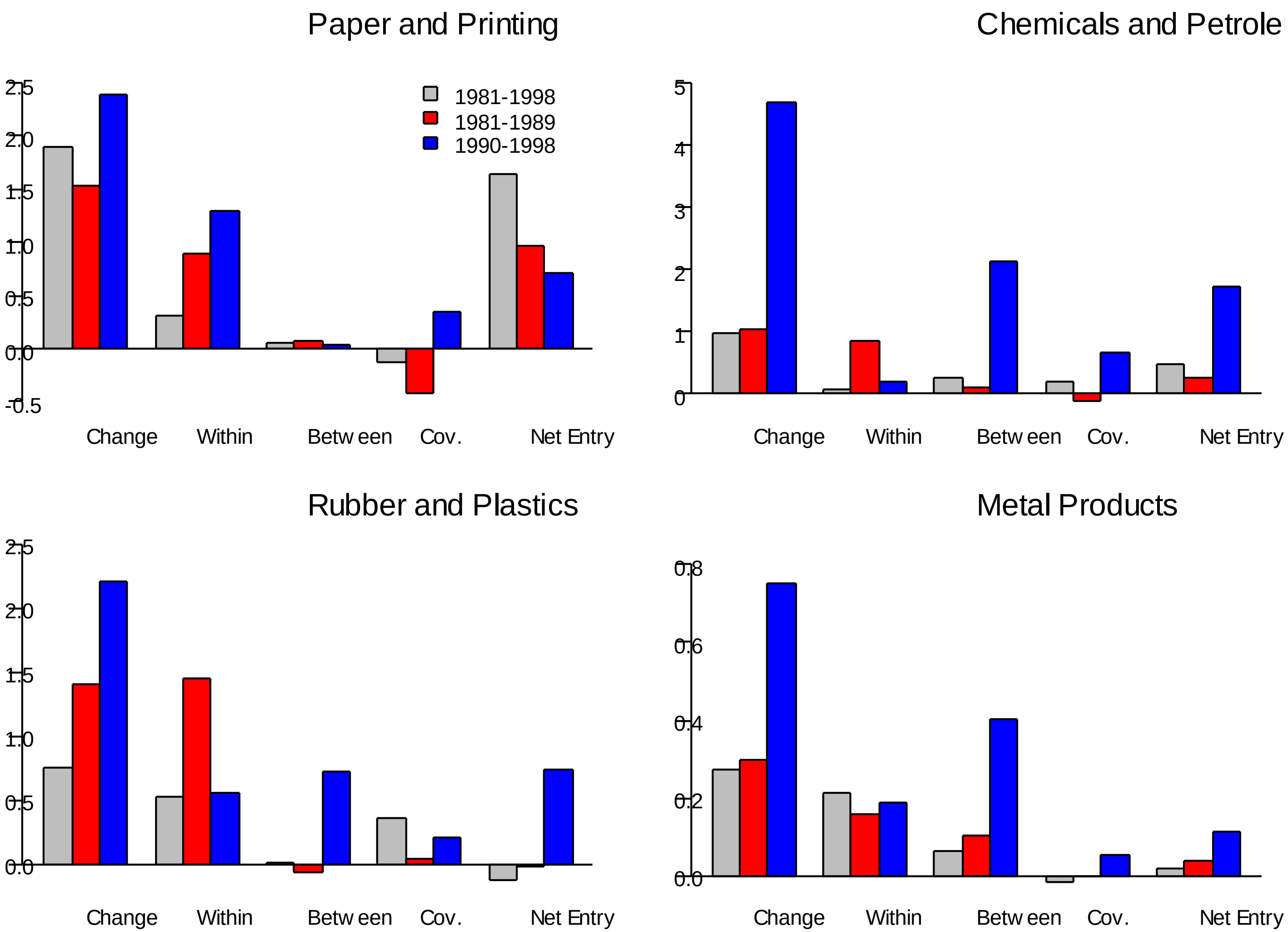
Table 2
Foster-Haltiwanger-Krizan Decomposition 1981-98 (employment shares)

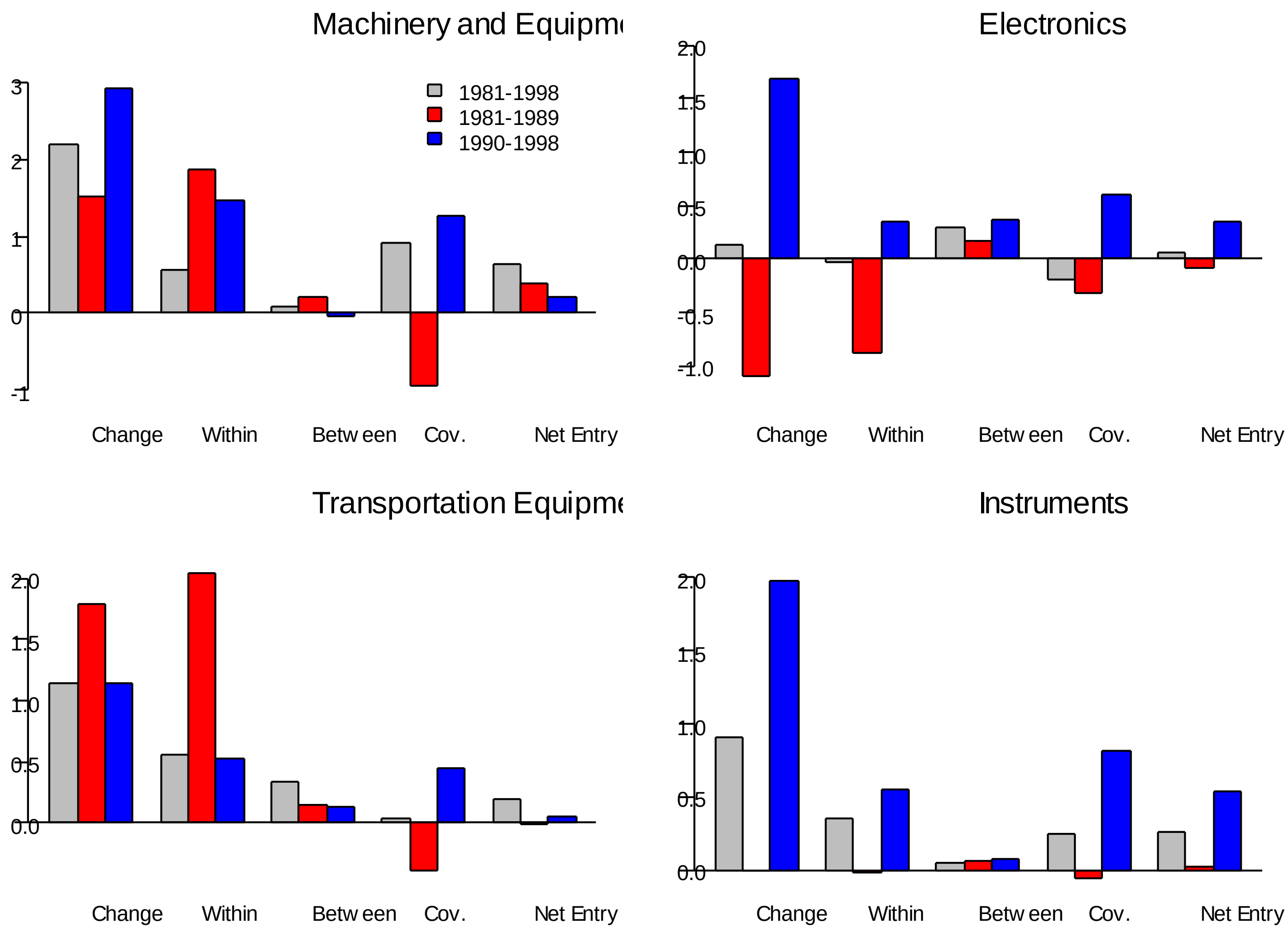
	Change	Within	Between	Cov.	Entry	Exit
Total Sample	0.7428	0.2654	0.0563	0.2066	0.1731	-0.0413
Construction	-0.1469	-0.0712	0.0298	-0.1902	0.0961	0.0114
Food and Beverages	0.1491	0.1195	-0.0344	0.1458	-0.0846	-0.0027
Textiles and Apparel	0.9975	0.5734	0.1571	-0.1970	0.3290	-0.1349
Paper and Printing	1.9066	0.3195	0.0649	-0.1263	1.7800	0.1314
Chemicals and Petroleum	0.9614	0.0705	0.2525	0.1770	0.3967	-0.0646
Rubber and Plastics	0.7528	0.5179	0.0099	0.3536	-0.0599	0.0688
Metal Products	0.2751	0.2112	0.0621	-0.0165	0.0717	0.0534
Machinery and Equipment	2.1975	0.5637	0.0790	0.9111	0.4631	-0.1805
Electronics	0.1253	-0.0322	0.2898	-0.1971	0.0190	-0.0458
Transportation Equipment	1.1350	0.5667	0.3450	0.0331	0.2198	0.0296
Instruments	0.9027	0.3495	0.0428	0.2455	0.2981	0.0333

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1998–1981).


Total Sample
1981-1998
1981-1989
1990-1998
2.0
1.5
1.0
0.5
0.0
Change
Within
Betw een
Cov.
Net Entry
Construction
1.0
0.5
0.0
-0.5
-1.0
Change
Within
Betw een
Cov.
Net Entry
Food and Beverages
0.6
0.4
0.2
0.0
-0.2
-0.4
Change
Within
Betw een
Cov.
Net Entry
Textiles and Apparel
2.0
1.5
1.0
0.5
0.0
Change
Within
Betw een
Cov.
Net Entry

Results for specific industries (2)




Machinery and Equipm
1981-1998
1981-1989
1990-1998
3
2
1
0
-1
Change
Within
Betw een
Cov.
Net Entry
Electronics
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Change
Within
Betw een
Cov.
Net Entry
Transportation Equipme
2.0
1.5
1.0
0.5
0.0
Change
Within
Betw een
Cov.
Net Entry
Instruments
2.0
1.5
1.0
0.5
0.0
Change
Within
Betw een
Cov.
Net Entry

- **Core results**

  - Productivity growth within firms is essential part of aggregate productivity growth
  - Between results seem to sustain the mechanism of replicator dynamics but have to be taken with care
  - Entering firms tend to have a productivity level above average while exiting firms show a productivity level below average
  - Success-breeds-success mechanism, coupling economical and technological improvements, take a non-negligible part of aggregate productivity development

IV. Direct approaches

- **Cantner U., J. Krüger, R. Söllner**

  Product Quality, Product Price and Share Dynamics in the German Compact Car Market

  Industrial and Corporate Change 21(5), 2012, 1085-1115

- **Not firms but products compete and become selected**

- **Fitness criterion for products: quality-price ratio**

  - e: relative quality price ratio
  - i: product i
  - t: time
  - q: characteristics 1 to J
  - p: price
  - a, b: aggregation weights

$$e_{it} = \frac{a_1 q_{it1} + a_2 q_{it2} + \ldots + a_J q_{itJ}}{p_{it}} = \frac{\mathbf{a}'\mathbf{q}_{it}}{bp_{it}}$$

  - Non-parametric frontier function approach (order-m, order -α)

- **Market demarcation instead of industry demarcation**

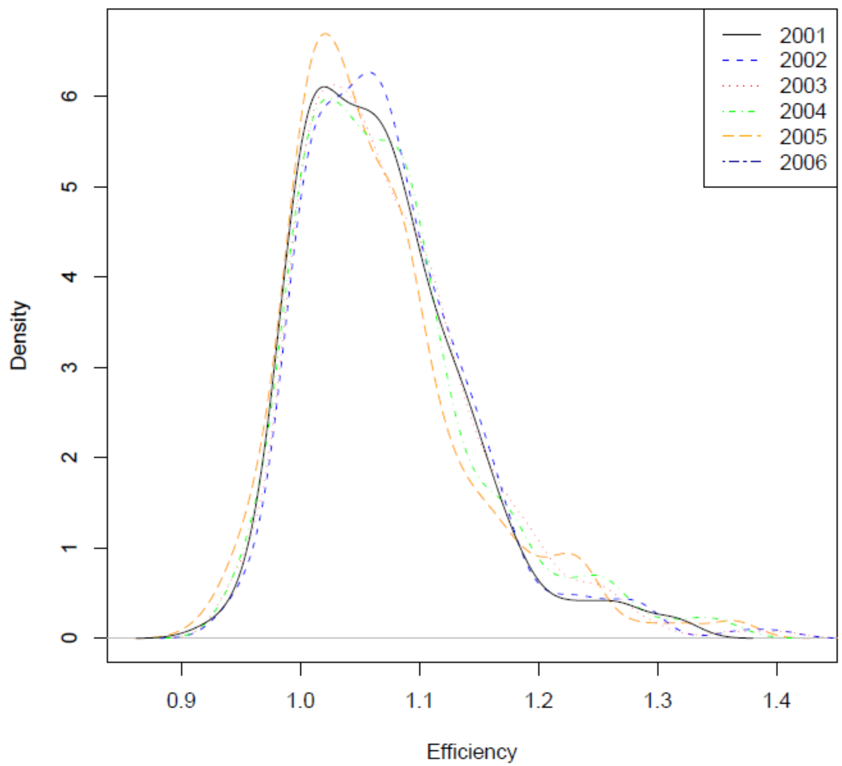
- **Sample**
  - Source: KBA
  - Period and Market: 2001-2006 German market for compact cars

- **Car characteristics**
  - Source ADAC
  - Out of 41 characteristics:
    - performance of a car: engine power (in kilowatts)
    - environmental friendliness: fuel efficiency via distance (in kilometers) per liter of petrol
    - loading capacity: luggage space (in liters)
    - safety: the dimension of a car (cubic meters)

- **Variables**
  - Fitness indicator FIND: share-weighted mean deviation of quality-price ratio
  - Age: age of the product
  - Firm dummies, price dummy, year dummies, country dummy

Year	Min	1st Quan.	Median	Mean	3rd Quan.	Max
2001	0.919	1.017	1.059	1.068	1.107	1.323
2002	0.941	1.022	1.062	1.074	1.113	1.401
2003	0.947	1.020	1.061	1.074	1.110	1.405
2004	0.938	1.016	1.061	1.073	1.105	1.364
2005	0.913	1.011	1.048	1.066	1.095	1.375

Figure 3: Kernel density estimates of car efficiency scores 2001-2005



- Theoretical model

$$\Delta s_{i,t+k} = s_{i,t+k} - s_{it} = \lambda s_{it}(e_{it} - \bar{e}_t)$$

$$\bar{e}_t = \sum_j s_{jt} e_{jt}$$

- Empirical model

$$\Delta s_{i,t+k} = \beta_1 FIND_{it} + \boldsymbol{\gamma}' \mathbf{x}_{it} + u_{it}$$

$$FIND_{it} = s_{it}(e_{it} - \bar{e}_t)$$

$$\mathbf{x}_{it} = (Age_{it}, VW_i, Opel_i, \dots, Year\ Dum.)'$$

k=1	t=2001	t=2002	t=2003	t=2004	t=2005
FIND	-1.3813	-0.1921	10.1254**	-3.0383	-1526
	(0.8603)	(0.72964)	(4.2198)	(2.7386)	(3.3214)
R^2	0.01864	0.3892	0.3255	0.05667	0.01718
Obs	326	286	300	313	336

k=2	t=2001	t=2002	t=2003	t=2004
FIND	-2.6381**	10.6850**	13.4381**	9.2037**
	(1.1093)	(5.3073)	(5.0123)	(3.7434)
R^2	0.03794	0.2551	0.1866	0.08587
Obs	326	286	300	313

k=3	t=2001	t=2002	t=2003
FIND	6.9514	12.9329**	10.6517*
	(6.4364)	(5.1055)	(5.5161)
R^2	0.08511	0.1642	0.06322
Obs	326	286	300

k=4	t=2001	t=2002
FIND	9.7523*	14.6005**
	(5.3163)	(7.3995)
R^2	0.0685	0.0831
Obs	326	286

k=5	t=2001
FIND	8.4671
	(5.7581)
R^2	0.0155

	k=1	k=2	k=3	k=4
FIND	0.0521	0.2870***	0.3257***	0.3392***
	(0.1199)	(0.0987)	(0.1005)	(0.1276)
Age	-0.1680***	-0.0822**	-0.0822***	-0.1363***
	(0.0276)	(0.0337)	(0.0337)	(0.0481)
VW	0.0390	-0.0512	0.0187	0.1821
	(0.1001)	(0.0892)	(0.1199)	(0.1945)
Opel	-0.2653***	-0.2634***	-0.2945***	-0.3644***
	(0.0677)	(0.0622)	(0.0755)	(0.0986)
Ford	0.0789	-0.0824	-0.0751	-0.3713***
	(0.0859)	(0.0948)	(0.0948)	(0.1198)
Daimler	-0.2219	0.1261	0.0094	-0.4910
	(0.2615)	(0.3556)	(0.4934)	(0.4317)
Audi	0.6282**	0.3184	-0.2581**	-0.2969*
	(0.2588)	(0.4032)	(0.1282)	(0.1787)
Toyota	-0.0260	0.5071**	0.7460**	0.6744
	(0.0903)	(0.2182)	(0.3590)	(0.4695)
Skoda	0.2127***	0.0496	0.1777	0.2978
	(0.0682)	(0.0720)	(0.1186)	(0.2012)
Citroen	0.0007	0.0021	0.0042	0.0785
	(0.0421)	(0.0443)	(0.0643)	(0.1245)
Renault	-0.1937***	-0.2111***	-0.1560***	-0.0789
	(0.0502)	(0.0515)	(0.0594)	(0.0552)
Peugot	0.0473	0.2410*	0.2439	0.4243*
	(0.0738)	(0.1373)	(0.1754)	(0.2494)
Year Dummies	yes	yes	yes	yes
R^2	0.053	0.118	0.132	0.122
F-statistic	5.64	5.27	5.87	5.13
p-value	0.000	0.000	0.000	0.000
Obs	1561	1225	912	612

	k=1	k=2	k=3	k=4
FIND	0.0658	-0.0949	-0.2404	-0.2537
	(0.0981)	(0.1135)	(0.1515)	(0.1838)
German x FIND	0.0178	0.4616***	0.6645***	0.6969***
	(0.1693)	(0.1613)	(0.1867)	(0.2292)
Year Dummies	yes	yes	yes	yes
R^2	0.007	0.111	0.137	0.108
F-statistics	0.15	3.45	5.19	4.85
p-value	0.988	0.004	0.000	0.002
Obs	1561	1225	912	612

	Low-price	High-price
FIND	0.3477***	0.3939
	(0.1060)	(0.3229)
Age	-0.1189**	-0.1645**
	(0.0544)	(0.0825)
VW	0.0100	0.2432
	(0.4252)	(0.1979)
Opel	-0.5570***	-0.1974*
	(0.1829)	(1117)
Ford	-0.3233***	-0.5519
	(0.1101)	(0.3420)
Daimler	0.4853	-0.8953*
	(0.5376)	(0.5173)
Audi	-	-0.2461
	-	(0.2329)
Toyota	0.8617	-0.1801
	(0.5801)	(0.1463)
Skoda	0.7965	0.1333
	(0.5269)	(0.2220)
Citroen	0.0218	0.1100
	(0.1558)	(0.1854)
Renault	-0.1239*	-0.1287
	(0.0639)	(0.1487)
Peugot	0.2787	0.7008
	(0.1972)	(0.7347)
Year Dummies	yes	yes
R^2	0.243	0.082
F-statistic	5.9	1.9
p-value	0.000	0.000
Obs	306	306

- **Core results**
  - Competition of products instead of firms
    ➔ car models
  - Market oriented approach instead of industry approach
    ➔ market for compact cars
  - Car models with considerably lower fitness than the market average lose market shares, while models with above-average fitness gain additional market shares
    ➔ evidence in favor of replicator dynamics
  - Even in case of various controls this result holds

Part IV

Problems in conception and measurement

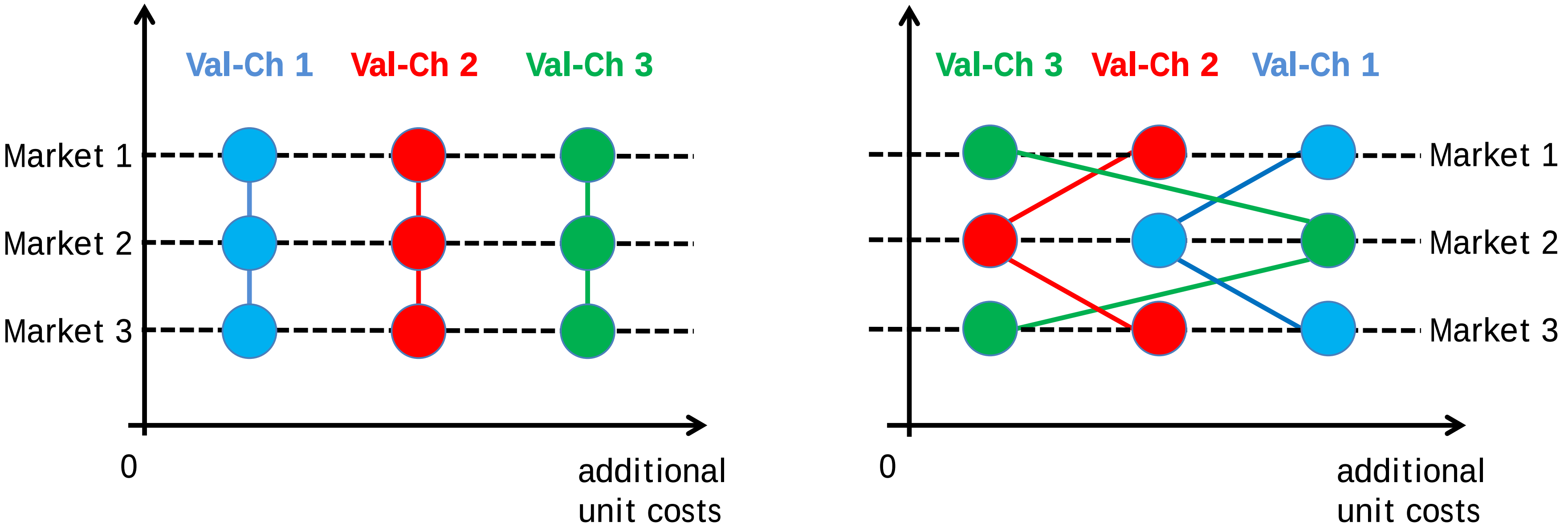
- **Empirical evidence for selection dynamics is rather difficult to find**

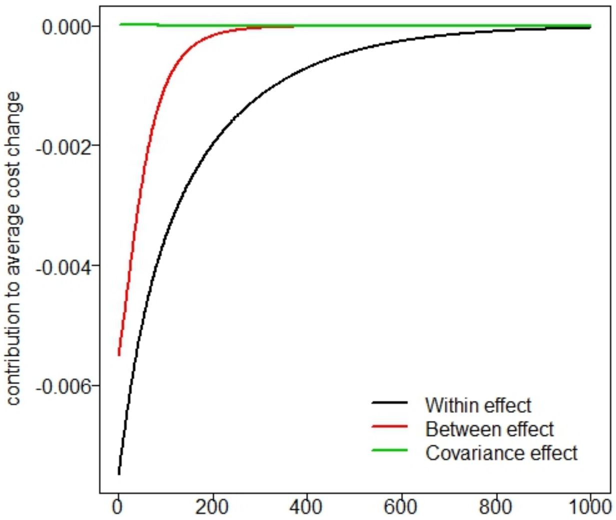
  - Replicator dynamics is simply an inappropriate analytical approach
  - Not all relationships among units of selection are taken into account
  - Variables used are not appropriate
  - Level of analysis is not appropriate

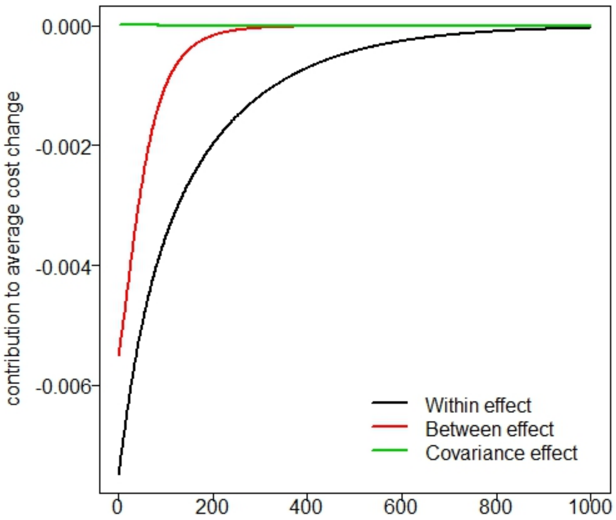
- **Problems with the empirics**
  - Technological dynamics higher than economic dynamics (market shares ➔ Cantner/Krüger 2006)
  - Mobility reducing effects ➔ mobility barriers
    - Market separation and niche markets (Klepper)
    - Sunk costs (Hölzl 2015)
  - Intra-firm compensating effects
    - Multiproduct firms (cross subsidization)
  - Inter-firm compensating effects - Interaction level
    - Collaboration
    - Connectivity via value chains

- **Extending the model by value chain relationships**

- **Cantner, U., I. Savin and S. Vannuccini, Replicator dynamics in value chains: explaining some puzzles of market selection, Friedrich Schiller University Jena, 2015, mimeo**


Val-Ch 1
Val-Ch 2
Val-Ch 3
Market 1
Market 2
Market 3
0
additional unit costs
Val-Ch 3
Val-Ch 2
Val-Ch 1
Market 1
Market 2
Market 3
0
additional unit costs


0.000
-0.002
-0.004
-0.006
contribution to average cost change
0
200
400
600
800
1000
Within effect
Between effect
Covariance effect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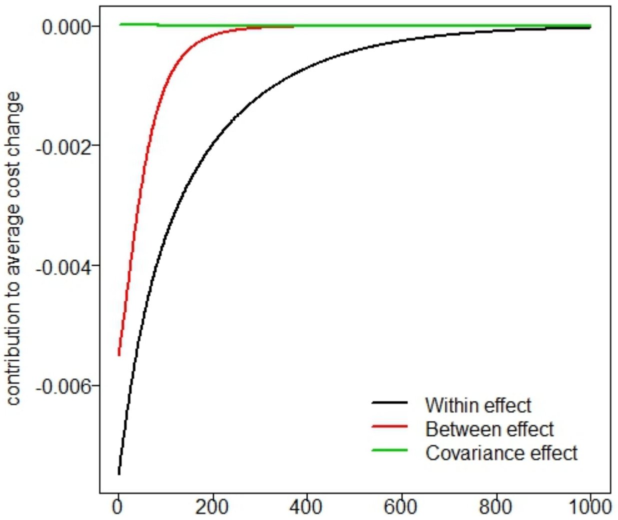
Within effect
Between effect
Covariance effect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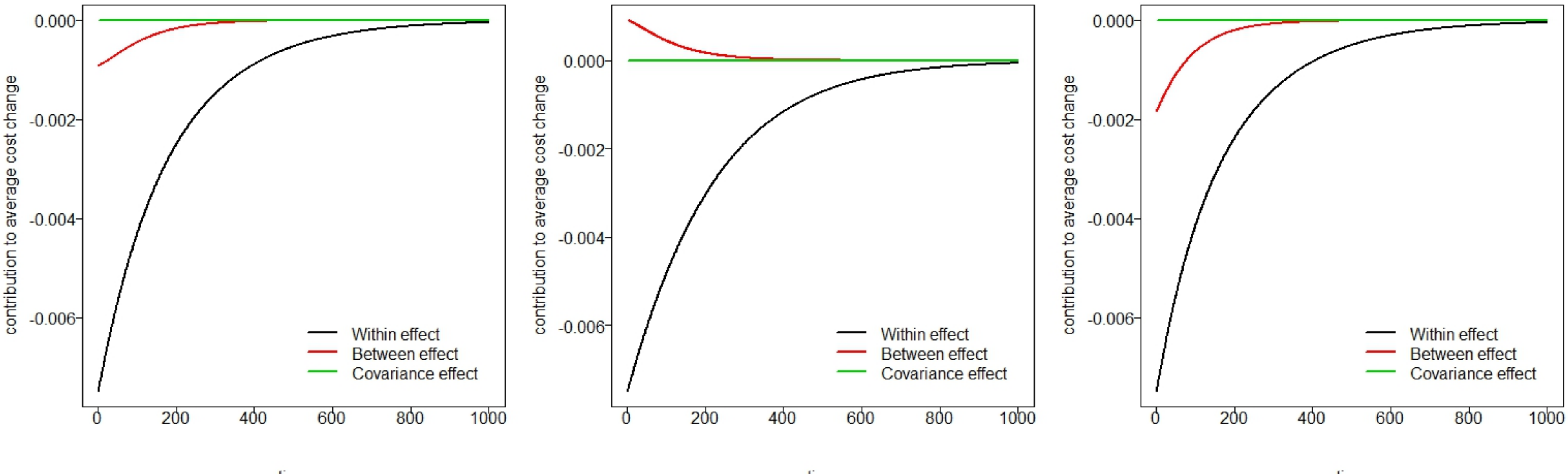
Within effect
Between effect
Covariance effect



contribution to average cost change
0.000
-0.002
-0.004
-0.006
0
200
400
600
800
1000
Within effect
Between effect
Covariance effect

There is more to be done!

Thank you for your attention!!

Back-up

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- Derivation of selection equation: $s_i \,, \quad i \in \{1,\ldots,n\}$
  - Market share of a firm: $s_i = y_i / y \,, \; y = \sum_{j=1}^{n} y_j \qquad \left[\Rightarrow \dot{y} = \sum_{j=1}^{n} \dot{y}_j \right]$
    - Productive capacity of a firm y_i
    - Productive capacity of all firms y
  - Change of market share: $\dot{s}_i = ds_i / dt$

$$\dot{s}_i = \frac{\dot{y}_i}{y} - \frac{y_i}{y^2}\dot{y} = \frac{\dot{y}_i}{y} - \frac{y_i}{y}\sum_{j=1}^{n}\frac{\dot{y}_j}{y} = \frac{y_i}{y}\frac{\dot{y}_i}{y_i} - \frac{y_i}{y}\sum_{j=1}^{n}\frac{y_j}{y}\frac{\dot{y}_j}{y_j}$$

$$= s_i g_i - s_i \cdot \sum_{j=1}^{n} s_j g_j = s_i \cdot (g_i - \bar{g})$$

  - Growth rate of a firm $g_i = \dot{y}_i / y_i$
  - (market share weighted) average growth rate $\bar{g}$

– Investment routine:
  - Unit profit
  - Investment of a constant share
  - Induced change production capacity

$$p - c_i$$

$$\lambda \in [0,1]$$

$$g_i = \lambda \cdot (p - c_i)$$

– Insert in selection equation:

$$\dot{s}_i = s_i \cdot \left(\lambda(p - c_i) - \sum_{j=1}^{n} s_j \cdot \lambda(p - c_j) \right)$$

$$= s_i \cdot \left(\lambda p - \lambda c_i - \lambda p + \lambda \cdot \sum_{j=1}^{n} s_j c_j \right)$$

$$= s_i \cdot (-\lambda c_i + \lambda \overline{c}) \ \text{ mit } \overline{c} = \sum_{j=1}^{n} s_j c_j$$

$$= s_i \cdot \lambda(\overline{c} - c_i)$$

$$f_i = -c_i$$

– result: selection equation
  with negative unit costs as fitness

– The change in average fitness in a population of competing firms is proportional to the variance in fitness

– Theorem: $\dot{\bar{c}} = -\lambda \cdot \sigma_c^2 \leq 0$

– proof:

$$\dot{\bar{c}} = \frac{d\bar{c}}{dt} = \sum_{i=1}^{n} \dot{s}_i c_i = \sum_{i=1}^{n} s_i \cdot \lambda(\bar{c} - c_i) \cdot c_i$$

$$= \lambda \cdot \sum_{i=1}^{n} \left(s_i c_i \bar{c} - s_i c_i^2 \right) = -\lambda \cdot \sum_{i=1}^{n} \left(s_i c_i^2 - s_i c_i \bar{c} + (s_i c_i \bar{c} - s_i c_i \bar{c}) \right)$$

$$= -\lambda \cdot \left(\sum_{i=1}^{n} \left(s_i c_i^2 - 2 s_i c_i \bar{c} \right) + \bar{c}^2 \right) = -\lambda \cdot \left(\sum_{i=1}^{n} s_i \left(c_i^2 - 2 c_i \bar{c} + \bar{c}^2 \right) \right)$$

$$= -\lambda \cdot \left(\sum_{i=1}^{n} s_i \left(c_i - \bar{c} \right)^2 \right) = -\lambda \cdot \sigma_c^2 \leq 0, \text{ da } \lambda > 0 \text{ and } \sigma_c^2 \geq 0 \quad \text{q.e.d.}$$

- **Internal consistency:** $$\sum_{i=1}^{n} s_{it} = 1 \Rightarrow \sum_{i=1}^{n} s_{i,t+1} = 1$$
  - continuous: $$\sum_{i=1}^{n} \dot{s}_i = \lambda \cdot \left(\sum_{i=1}^{n} s_i f_i - \sum_{i=1}^{n} s_{it} \cdot \bar{f} \right) = \lambda \cdot (\bar{f} - 1 \cdot \bar{f}) = 0$$
  - discrete: $$\sum_{i=1}^{n} s_{i,t+1} = \sum_{i=1}^{n} s_{it} + \lambda \cdot \left(\sum_{i=1}^{n} s_{it} f_{it} - \sum_{i=1}^{n} s_{it} \cdot \bar{f}_t \right) = 1 + \lambda \cdot (\bar{f}_t - 1 \cdot \bar{f}_t) = 1$$

$$\Delta\overline{a}_t^s = \overline{a}_t^s - \overline{a}_{t-k}^s = \sum_{i\in C\cup N} s_{it}a_{it} - \sum_{i\in C\cup X} s_{it-k}a_{it-k}$$

$$= \sum_{i\in C}(s_{it}a_{it} - s_{it-k}a_{it-k}) + \sum_{i\in N} s_{it}a_{it} - \sum_{i\in X} s_{it-k}a_{it-k}$$

$$= \sum_{i\in C}((s_{it-k} + \Delta s_{it})(a_{it-k} + \Delta a_{it}) - s_{it-k}a_{it-k}) + \sum_{i\in N} s_{it}a_{it} - \sum_{i\in X} s_{it-k}a_{it-k}$$

$$= \sum_{i\in C}(s_{it-k}a_{it-k} + s_{it-k}\Delta a_{it} + \Delta s_{it}a_{it-k} + \Delta s_{it}\Delta a_{it} - s_{it-k}a_{it-k}) + \sum_{i\in N} s_{it}a_{it} - \sum_{i\in X} s_{it-k}a_{it-k}$$

$$= \sum_{i\in C} s_{it-k}\Delta a_{it} + \sum_{i\in C}\Delta s_{it}a_{it-k} + \sum_{i\in C}\Delta s_{it}\Delta a_{it} + \sum_{i\in N} s_{it}a_{it} - \sum_{i\in X} s_{it-k}a_{it-k} \quad + 0$$

$$= \sum_{i\in C} s_{it-k}\Delta a_{it} + \sum_{i\in C}\Delta s_{it}a_{it-k} + \sum_{i\in C}\Delta s_{it}\Delta a_{it} + \sum_{i\in N} s_{it}a_{it} - \sum_{i\in X} s_{it-k}a_{it-k} \quad + \sum_{i\in X} s_{it-k}\overline{a}_{t-k}^s - \sum_{i\in N} s_{it}\overline{a}_{t-k}^s - \sum_{i\in C}\Delta s_{it}\overline{a}_{t-k}^s$$

$$= \sum_{i\in C} s_{it-k}\Delta a_{it} + \sum_{i\in C}\Delta s_{it}a_{it-k} - \sum_{i\in C}\Delta s_{it}\overline{a}_{t-k}^s + \sum_{i\in C}\Delta s_{it}\Delta a_{it} + \sum_{i\in N} s_{it}a_{it} - \sum_{i\in N} s_{it}\overline{a}_{t-k}^s - \left(\sum_{i\in X} s_{it-k}a_{it-k} - \sum_{i\in X} s_{it-k}\overline{a}_{t-k}^s\right)$$

$$= \sum_{i\in C} s_{it-k}\Delta a_{it} + \sum_{i\in C}\Delta s_{it}(a_{it-k} - \overline{a}_{t-k}^s) + \sum_{i\in C}\Delta s_{it}\Delta a_{it} + \sum_{i\in N} s_{it}(a_{it} - \overline{a}_{t-k}^s) - \sum_{i\in X} s_{it-k}(a_{it-k} - \overline{a}_{t-k}^s)$$

$$\overline{a}_{t-k}^s(1-1) = \overline{a}_{t-k}^s\left(\sum_{i\in C\cup X} s_{it-k} - \sum_{i\in C\cup N} s_{it}\right) =$$

$$\overline{a}_{t-k}^s\left(\sum_{i\in X} s_{it-k} + \sum_{i\in C} s_{it-k} - \sum_{i\in N} s_{it} - \sum_{i\in C} s_{it}\right) =$$

$$\overline{a}_{t-k}^s\left(\sum_{i\in X} s_{it-k} - \sum_{i\in N} s_{it} - \sum_{i\in C}(s_{it} - s_{it-k})\right) =$$

$$\overline{a}_{t-k}^s\left(\sum_{i\in X} s_{it-k} - \sum_{i\in N} s_{it} - \sum_{i\in C}\Delta s_{it}\right) =$$

$$\sum_{i\in X} s_{it-k}\overline{a}_{t-k}^s - \sum_{i\in N} s_{it}\overline{a}_{t-k}^s - \sum_{i\in C}\Delta s_{it}\overline{a}_{t-k}^s = 0$$