Growth and Labor Reallocation: Vertical versus Horizontal Innovation

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This paper: Labor Reallocation and Growth

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  Innovation by firms currently existent in the market
  ⇒ Growth w/o firm replacements

- **Horizontal Innovation**:

  Innovation by firms new to the market
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– **Vertical Innovation**:


VS


Generations of Hand Drills by Bosch

⇒ Replaces its own product

⇒ Small net labor turnover

– **Horizontal Innovation**:

BOSCH +


Bosch's expansion to E-Bike Motors

⇒ Replaces others' products

⇒ Large net labor turnover

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This paper makes this distinction within a unified framework.

⇒ But, how to identify these innovation types separately?

Research Question

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  - Vertical innovation accounts for most productivity growth.

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  - Vertical innovation accounts for most productivity growth.

  $\Rightarrow$ Labor reallocation does not respond elastically to aggregate growth.
- **Application**:
  - The Hartz labor market reform improves productivity growth and welfare additionally through more vertical innovation.
  - Job destruction rates do not increase after the reform.

Literature Review

- Schumpeterian Growth Model:
  - Aghion and Howitt (1992), Klette and Kortum (2004), Lentz and Mortensen (2008), Acemoglu et Akcigit (2012), Acemoglu and Cao (2015), Acemoglu et al. (2018), Akcigit and Kerr (2018), Atkeson and Burstein (2019), Akcigit, Alp, and Peters (2021), Peters (2020)
- Technological Change and Employment:
  - Davis and Haltiwanger (1999), Postel-Vinay (2004), Pissarides and Vallanti (2007), Hornstein, Krussel, and Violante (2007), Michau (2013), Decker et al. (2014, 2016), Coles and Mortensen (2016), Faberman (2017), Engbom (2019), Garcia-Macia et al. (2019)
- Empirical Measures of Innovation:
  - Kortum (1997), Aghion et al. (2005, 2009), Hashmi (2013), Seru (2014), Kogan et al. (2017), Akcigit and Kerr (2018), Dorn et al. (2020), Argente et al. (2020), Webb (2020), Zolas et al. (2021)
- Effect of the Hartz Reform:
  - Krause and Uhlig (2012), Launov and Wälde (2013, 2016), Bradley and Krüger (2019), Hochmuth et al. (2021), Bauer and King (2019)

Structure

- ★ **New Facts from Survey Measure**
  - Data Description
  - Innovation and Establishment Behavior
- ★ **Model**
- ★ **Calibration**
- ★ **Counterfactual Analysis**

Measure of Innovation

- This paper proposes survey-based measures of innovation.
- $\neq$ patent-based measures of innovation
  - Include service & utility sectors.
  - Vertical and horizontal innovations distinguished by survey questions.

Innovation - Details

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  - Did your establishment improve or further develop a product or service which had previously been part of your portfolio?

  & Did you develop or implement procedures which have noticeably improved production processes or services?

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- **Horizontal Innovation**:
  - Did your establishment start to offer a product/service new to the establishment?

Innovation - Details

German Establishment Panel Survey (IAB-BP)

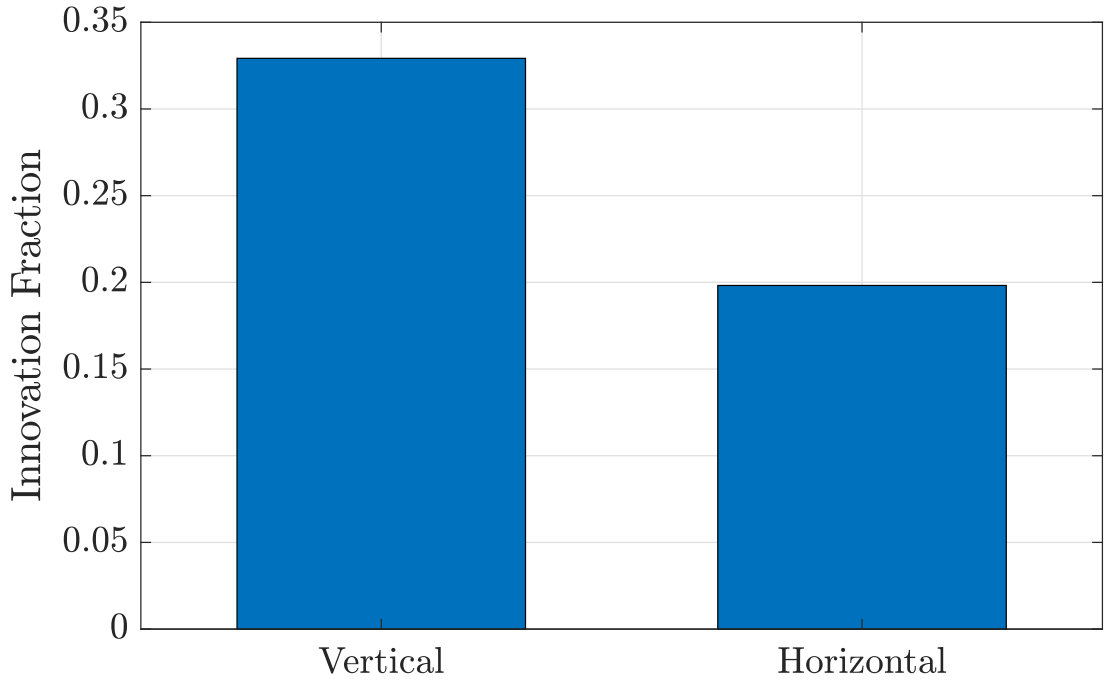
- Annual survey of establishments in Germany.
- Coverage
  - Starts in 1993 for West Germany and 1996 for East Germany, currently until 2017.
  - Representative random sample stratified according to establishment size, industry, and federal state.
  - Approximately 16,000 establishments per year.
- Innovation module started in the 2008 survey.
- Substantial changes in covered variables and questions in 2002.

  $\Rightarrow$ Restrict my samples to the post-2002 period.
- IAB-BP can be linked to the administrative employer-employee matched data.
  - Employment, Imputed daily wage of full time employees as of June 30.

Data Description Comparison to Patent Data

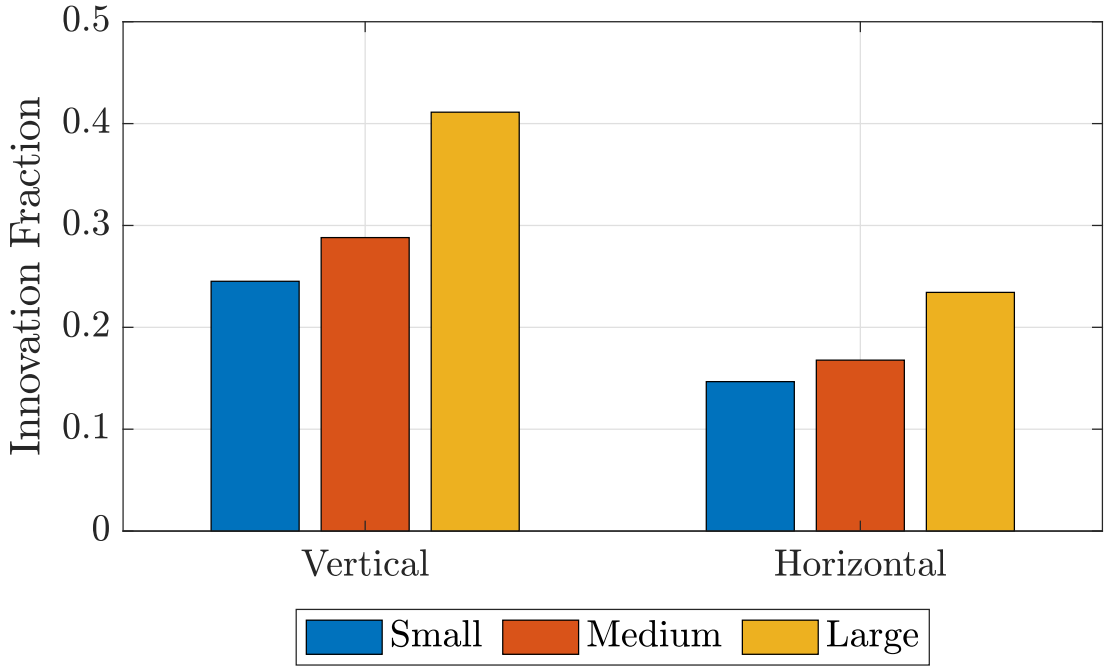
Fraction of Innovating Establishments

- More firms innovating vertically than horizontally.



Lagged Size and Fraction of Innovating Est.

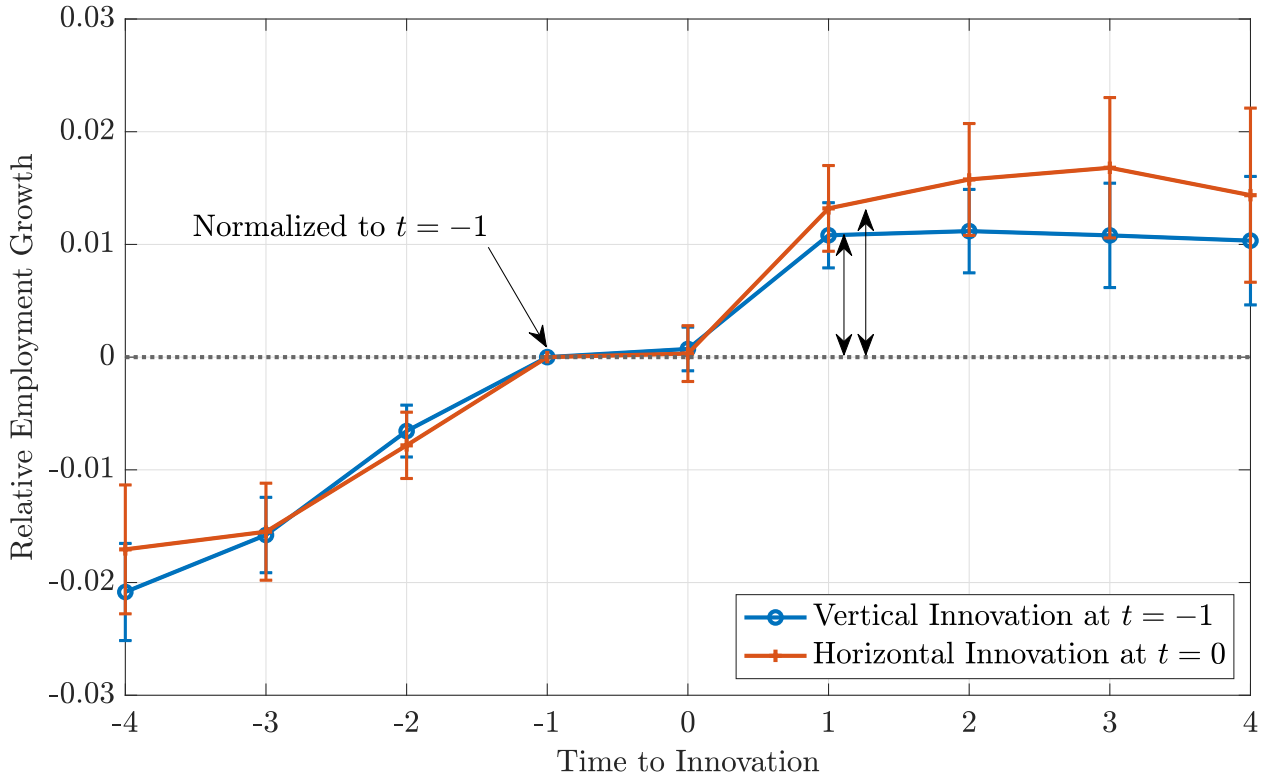
- Larger establishments are more likely to innovate.



Innovation and Employment Growth

- Innovating firms grow faster relative to the average establishment.

$\Rightarrow$ Labor reallocation from job creation.



Innovation Dynamics

Summary of Regression Exercise

- Effect of Innovation on Innovating establishments Regression Results
  - Vertical innovation ⇒ smaller and temporary increase in emp.
  - Horizontal innovation ⇒ larger and persistent increase in emp.

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- Effect of Innovation on Competitors Regression Results
  - Vertical innovation by competitors ⇒ small decrease in emp.
  - Horizontal innovation by competitors ⇒ large decrease in emp.
- Both vertical and horizontal innovations are labor-augmenting.
- Horizontal innovation churns labor more than vertical innovation.

Other Regression Results

Structure

- **New Facts from Survey Measure**
- **Model**
  - Overview
  - Value
  - Equilibrium
  - Growth and Labor Reallocation
- **Calibration**
- **Counterfactual Analysis**

Model - Overview

- **Goal**
  - Construct a framework to quantify the impact of firm innovation behavior on macro outcomes such as growth and job flow rates.
  - Incorporate endogenous horizontal and vertical innovation choices into the BGP à la Acemoglu and Cao (2015) and Akcigit and Kerr (2018).
- **Agents**
  - Representative households consume final goods and supply labor.
  - Competitive final good producers combine intermediate inputs.
  - Intermediate good producers hire workers & innovate vertically and horizontally on multiple product lines.
- **Technology**
  - A product line produces intermediate inputs using labor.
  - Intermediate inputs are differentiated & aggregated with CES.

Final Good Production and Factor Demand

- The final good is produced by

$$Y_t = \left(\int_0^1 a_{jt} y_{jt}^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}},$$

where $\sigma > 1$ is the elasticity of substitution.

- An intermediate good producer solves

$$p_{jt} = \arg\max_p \{ y_{jt}(p)p - y_{jt}(p)W_t \}.$$

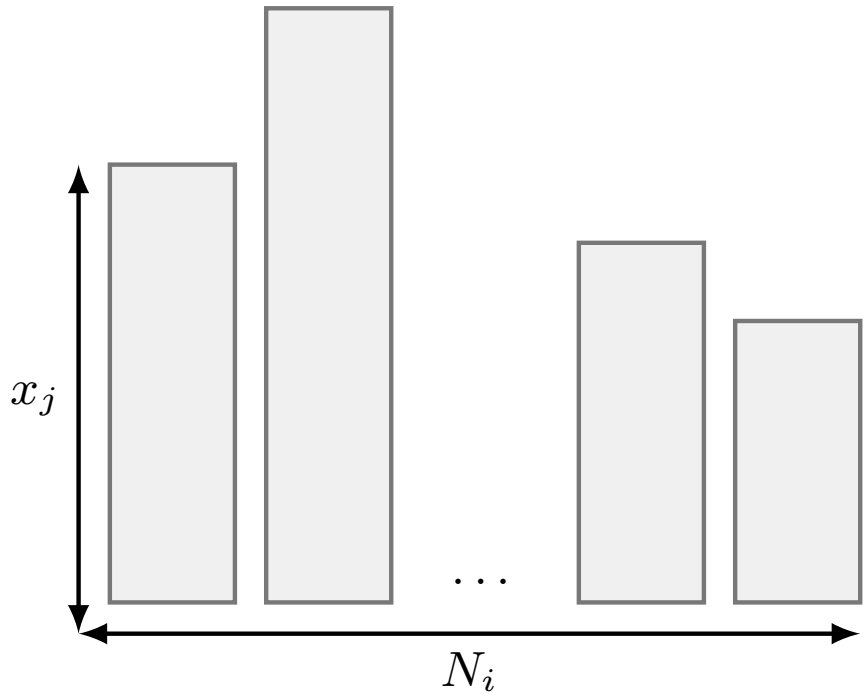
- The solution gives the following profit and production labor demand.

$$Y_t \pi(x_{jt}) := Y_t x_{jt}/\sigma, \quad W_t l^p(x_{jt}) = (\sigma - 1) Y_t x_{jt}/\sigma$$

where $x_{jt} := a_{jt}^\sigma / A_t^{\sigma-1}$ and $A_t := \left(\int_0^1 a_{jt}^\sigma dj \right)^{\frac{1}{\sigma-1}}$.

- For the zero-profit of final goods producers, $W_t = A_t \frac{\sigma-1}{\sigma}$.

Graphics: Revenue and Depreciation



- Firm state $= \{x_j\}_{j=1}^{N_i}$.

  N_i - number of product lines

  x_j - relative quality

- Without any firm-level shock,

$\Rightarrow$ x depreciates over time with A_t growing over time.

$\Rightarrow$ Nothing happens to N_i.

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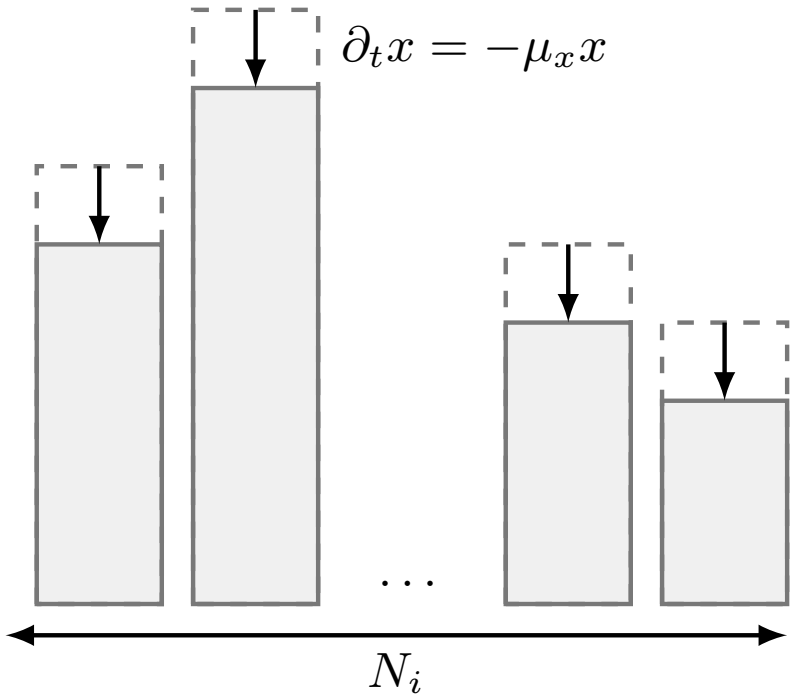

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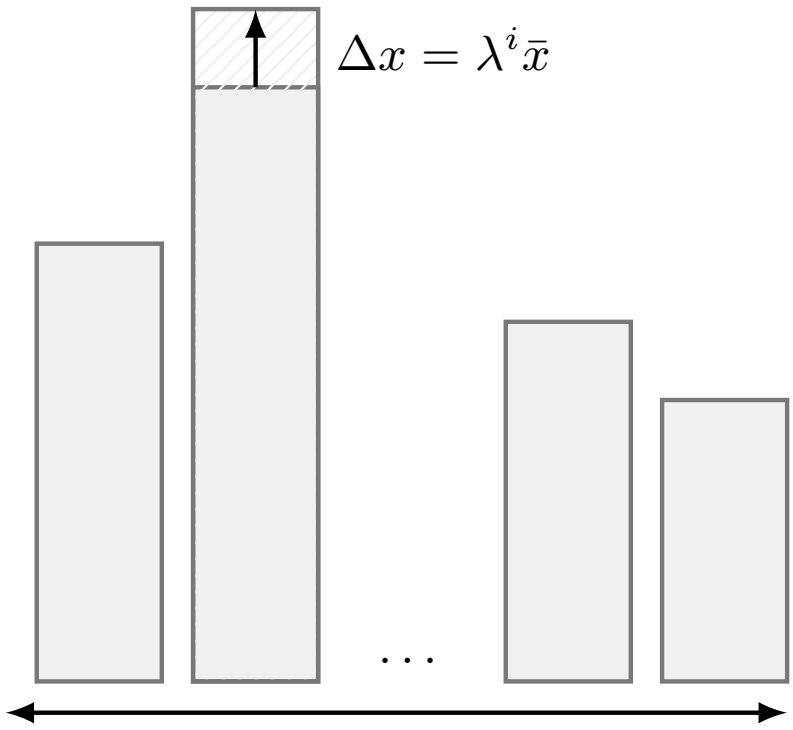
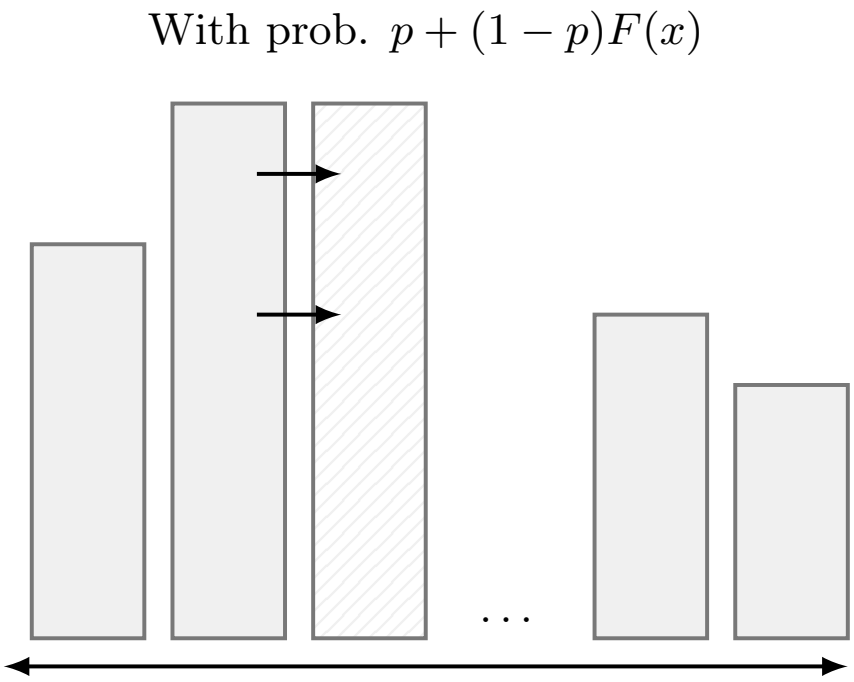
Graphics: Vertical Innovation



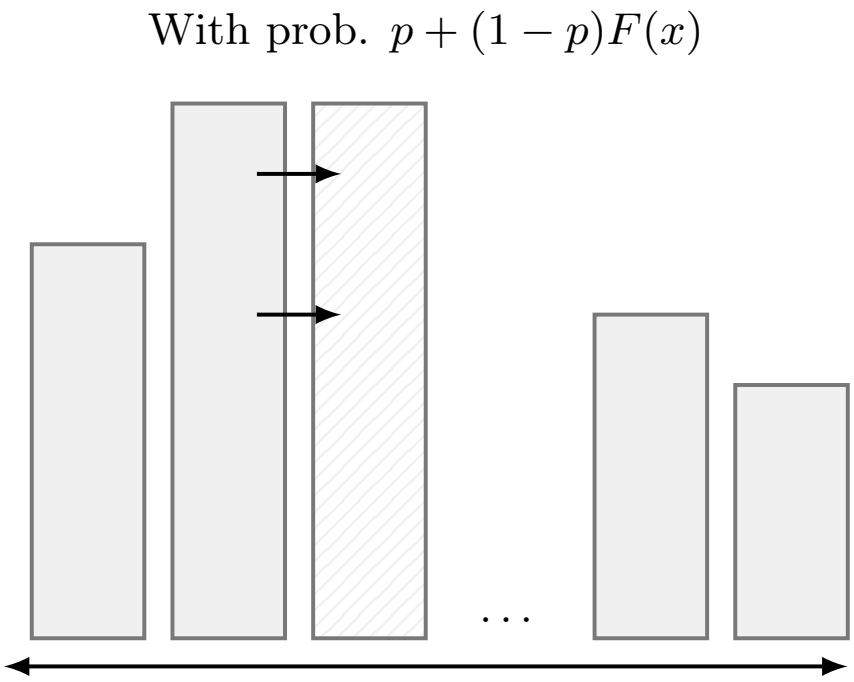
- A firm can vertically innovate with a Poisson rate ξ at the labor cost of $W_t c_\xi(\xi)$.
- Vertical innovation choice is product-line-specific.
- $c'_\xi, c''_\xi > 0$
- Vertical innovation increases relative productivity of a product line by $\lambda^i \bar{x}$.

Graphics: Horizontal Innovation



- A firm can horizontally innovate with a Poisson rate ζ at the labor cost of $W_t c_\zeta(\zeta)$.
- Horizontal innovation adds a new product line having the same productivity.
- With probability p, it is matched to a vacant product line.

Graphics: Horizontal Innovation



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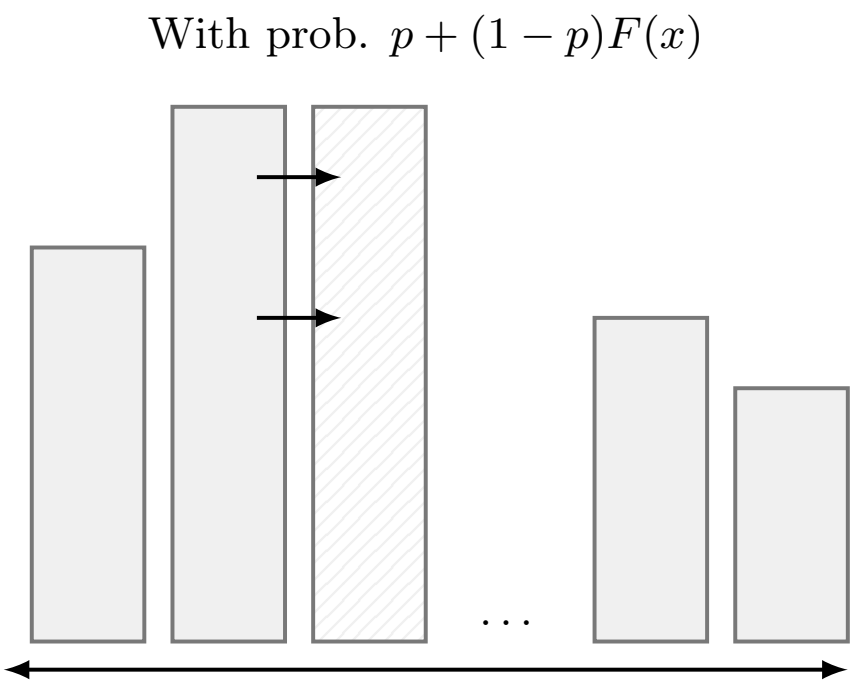
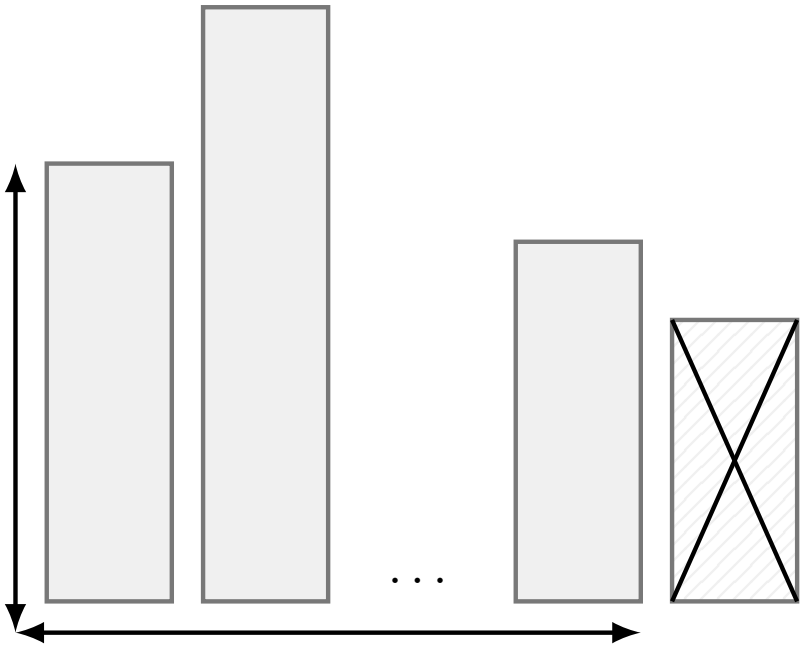


- A firm can horizontally innovate with a Poisson rate ζ at the labor cost of $W_t c_\zeta(\zeta)$.
- Horizontal innovation adds a new product line having the same productivity.
- With probability $1-p$, it is matched to an occupied product line.
- It must be more productive than the matched firm for prod.

Graphics: Creative Destruction



- A creative destruction shock at rate $\tau(x)$.
- Matched firms replace old firms if they are more productive.

$\Rightarrow$ $\tau'(x) < 0$.

- Horizontal & entrant innovation

$\Rightarrow$ creative destruction shock.

More Graphical Illustration

Firm Values and Stationary Value

- The profits are summed over product lines.
- All decisions & shocks independent across product lines (except exits).

$\Rightarrow$ Firm value = sum of product line values.

$$\mathfrak{V}_t\left(\{x_j\}_{j=1}^{N_i}\right) = \sum_{j=1}^{N_i} V_t\left(x_j\right)$$

- On the BGP, all input prices, output, and profits grow at g_Y.

$\Rightarrow$ $v_t(x) := V_t(x)/Y_t$ is a time-invariant function of x.

Firm and Product Line Values

- The stationary component of a product line value

$$
\begin{aligned}
(\rho+\delta+\tau(x))\,v(x) = \max_{\xi,\zeta\geq 0}\Bigg\{ & \underbrace{\pi(x)}_{\text{profit}} - \underbrace{g_x x v'(x)}_{\text{depreciation}} \\
& - wc_\xi(\xi) + \xi \underbrace{\left(v\left(x+\lambda^i \bar{x}\right) - v(x) \right)}_{\text{return to V.I.: better quality}} \\
& - wc_\zeta(\zeta) + \zeta \underbrace{(p+(1-p)F(x))\,v(x)}_{\text{return to H.I.: additional line}} \\
& - (\tau(x)+\delta)\,\kappa x \Bigg\}.
\end{aligned}
$$

where wc_ξ and wc_ζ are the labor costs of vertical and horizontal innovation.

Definition of BGP Equilibrium

- The Balanced Growth Path (BGP) equilibrium is defined as value function $v(x)$; policy function $\xi(x)$, $\zeta(x)$; product line distribution $f(x)$; creative destruction rates $\tau(x)$; growth rates μ_x, μ_Y; entry rate χ; constant wage level w; a constant interest rate r; the constant labor supply L such that

  1. The representative household optimizes.
  2. Value function and policy function satisfy the HJB equations.
  3. The distribution of product lines over x stays constant. The mass of product lines is also time-invariant.
  4. The free entry condition is met to pin down entry rate, χ.
  5. Growth and creative destruction rates are time-invariant.
  6. Final goods and labor markets are cleared.

RepH Distribution Creative Destruction Free Entry & Labor Market Clearing

Product-line Innovation and Reallocation

- Suppose vertical innovation happens to a product line with x.
  - Increase in the productivity of a product line: $\lambda^i \bar{x}$.
  - Job creation of the innovating firm:

$$\lambda^i \bar{x} \frac{(\sigma - 1)}{w\sigma} + (c_\zeta(x + \lambda^i \bar{x}) - c_\zeta(x)) + (c_\xi(x + \lambda^i \bar{x}) - c_\xi(x))$$

  - Job destruction of non-innovating firms:

$$\underbrace{g_x \tilde{x} \left(\frac{(\sigma - 1)}{w\sigma} + c'_\zeta(\tilde{x}) + c'_\xi(\tilde{x}) \right)}_{\text{Obsolescence}}$$

Product-line Innovation and Reallocation

- Horizontal innovation & creative destruction
  - Assume the same productivity increase: $\lambda^i \bar{x}$
  - Job creation of the innovating firm:

$$\frac{x(\sigma-1)}{w\sigma} + \lambda^i \bar{x} \frac{(\sigma-1)}{w\sigma} + c_\zeta(x + \lambda^i \bar{x}) + c_\xi(x + \lambda^i \bar{x})$$

  - Job destruction of non-innovating firms:

$$\text{Obsolescence} + \underbrace{\frac{x(\sigma-1)}{w\sigma} + c_\zeta(x) + c_\xi(x)}_{\text{Creative Destruction}}$$

Product-line Innovation and Reallocation

- For the same productivity increase,
  horizontal innovation reallocates more labor *across* firms by

$$l(x) := \frac{x(\sigma - 1)}{w\sigma} + c_\zeta(x) + c_\xi(x)$$

- $l(x) =$ labor demand of a product line with x.

Aggregate Job Creation

- For a sufficiently small Δ, job creation happens in three cases
  - Vertical Innovation: job creation by $l(x+\lambda^i\bar{x}) - l(x) - \Delta g_x x l'(x)$
  - Horizontal Innovation: job creation by $l(x) - \Delta g_x x l'(x)$
  - Entry: job creation by $l(x+\lambda^e\bar{x})$
- Average job creation rate is approximately

$$\int \xi(x)(l(x+\lambda^i\bar{x}) - l(x) - \Delta g_x x l'(x))dF(x)$$
$$+\int \zeta(x)(p+(1-p)F(x))(l(x) - \Delta g_x x l'(x))dF(x)$$
$$+\chi\int (p+(1-p)F(x+\lambda^e\bar{x}))l(x+\lambda^e\bar{x})dF(x)$$

- Increase in ξ, ζ (Job creation $\Uparrow$) $\Rightarrow$ $g_x \uparrow$ (Job creation $\Downarrow$)
- Quantitatively, ζ creates more job creation for a fixed Δg_x.

Aggregate Job destruction

- Likewise, job destruction happens in three cases
  - Exit: job destruction by $l(x)$
  - Creative Destruction: job destruction by $l(x)$
  - Nothing: job destruction by $\Delta g_x x l'(x)$
- Average job destruction rate is approximately

$$\int (\tau(x) + \delta) l(x) dF(x) + \int (1 - \bar{\zeta} - \bar{\xi} - \bar{\chi} - \bar{\tau} - \delta) \Delta g_x x l'(x) dF(x)$$

  $\bar{\xi} := \int \xi(x) dF(x)$ and $\bar{\zeta} = \int \zeta(x)(p + (1-p)F(x)) dF(x)$ are the mass of vertically and horizontally innovating establishments, respectively.
- Increase in ξ, ζ (Job Destruction $\Downarrow$) $\Rightarrow$ $g_x \uparrow$ (Job Destruction $\Uparrow$)
- Increase in $\zeta \Rightarrow \tau \uparrow$ (Job Destruction $\Uparrow$)

Structure

- **New Facts from Survey Measure**
- **Model**
- **Calibration**
  - Identification
  - Model Fit
- **Counterfactual Analysis**

Calibration - Step 1

- Iso-elastic innovation cost functions

$$c_\xi(\xi) = c_\xi \frac{\epsilon_\xi}{\epsilon_\xi + 1} \xi^{\frac{\epsilon_\xi + 1}{\epsilon_\xi}}$$

$$c_\zeta(\zeta) = c_\zeta \frac{\epsilon_\zeta}{\epsilon_\zeta + 1} \zeta^{\frac{\epsilon_\zeta + 1}{\epsilon_\zeta}}$$

$$c_\chi(\chi) = c_\chi \chi^{\frac{\epsilon_\chi + 1}{\epsilon_\chi}}$$

- q^v, q^h: prob. of successful innov. conditional on survey 'yes'.
- Within firm, independent innovation events across product-lines.
- Two model parameters externally matched. One for normalization.

Moment	Meaning	Value	Source
r	Discount Rate (%)	8/12	Average Stock Market Rate of Return
δ	Exogenous Exit Rate (%)	1/12	Fackler et al. (2013)
$\bar{L}$	Labor Supply in the Steady State	0.38	Wage Normalization

Calibration - Step 2

- 10 moments matched for 10 parameters

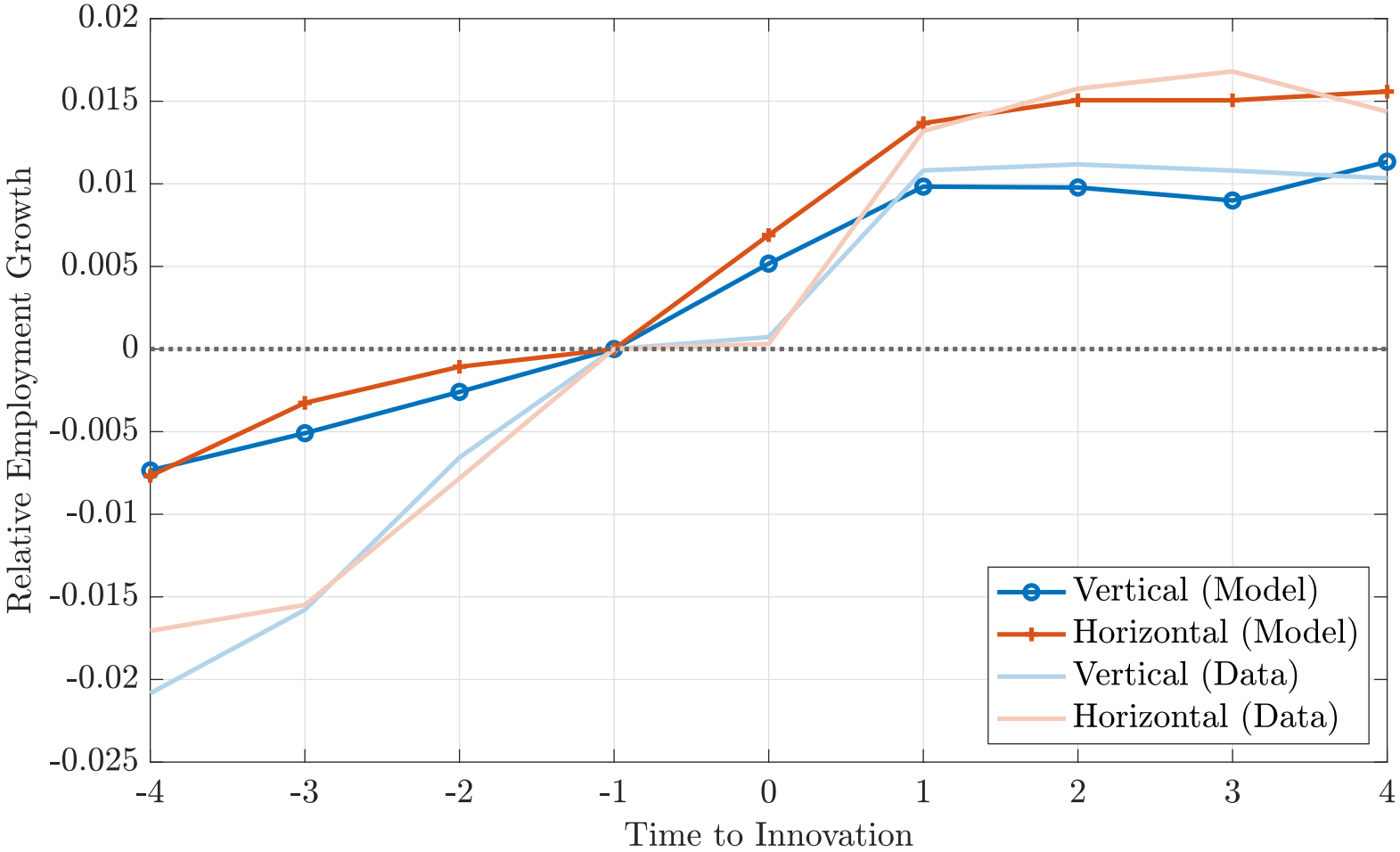
Moment	Data	Model	Target
Growth Rate (%)	1.3	1.3	λ^i
Fraction of Vertical Innovation (%)	29.4	29.4	c_ξ
Fraction of Horizontal Innovation (%)	17.3	17.4	c_ζ
Fraction of Vertical Innovation (Medium - Small, ppt)	3.6	3.4	ϵ_ξ
Fraction of Horizontal Innovation (Medium - Small, ppt)	2.0	1.3	ϵ_ζ
Employment Growth (Vertical - Average, ppt)	1.1	1.1	q^v
Employment Growth (Horizontal - Average, ppt)	1.3	1.4	q^h
Employment Growth (No Innovation - Average, ppt)	-1.6	-1.4	σ
Employment Share of Establishment Age ≤ 1 (%)	1.1	1.5	λ^e
Establishment Share of Establishment Age ≤ 1 (%)	1.9	1.9	χ

Calibration Results

	Parameter	Value
λ^i	Step Size of Vertical Innovation (%)	2.7
λ^e	Step Size of Entrant Innovation (%)	3.1
σ	Elasticity of Substitution across Products	1.4
c_ξ	Vertical Innovation Cost Shifter	2039
ϵ_ξ	Vertical Innovation Cost Elasticity	0.53
c_ζ	Horizontal Innovation Cost Shifter	2.61e+06
ϵ_ζ	Horizontal Innovation Cost Elasticity	0.31
$12 \times \chi$	Annual Share of Entrant Draws (%)	0.92
q^h	Probability of Successful Expansion (%)	3.1
q^v	Probability of Successful Improvement (%)	55

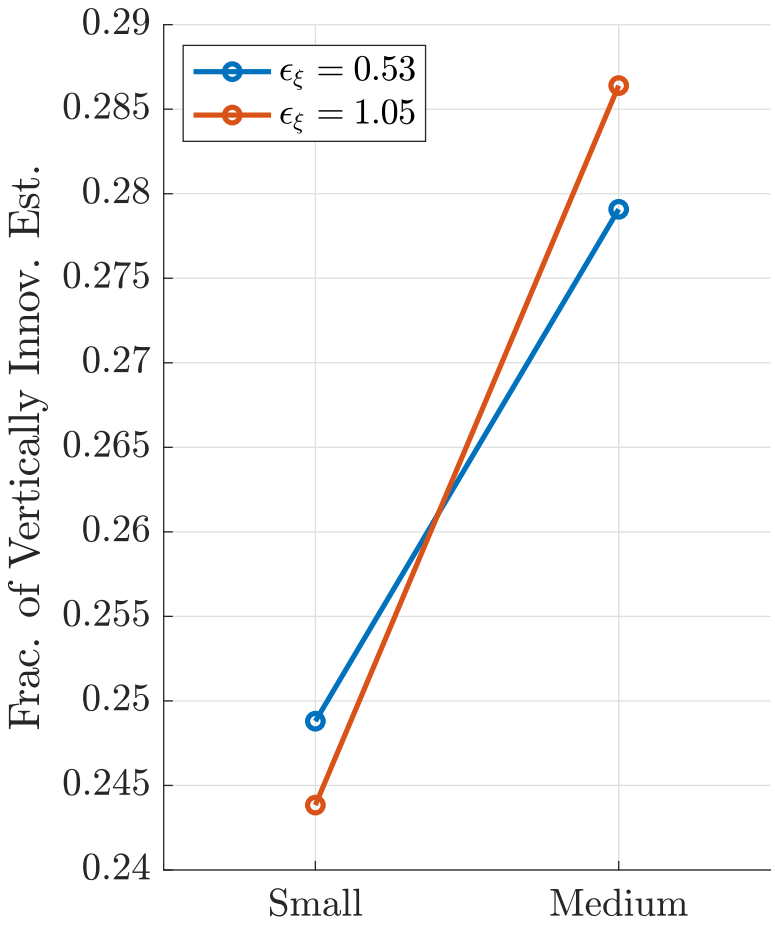
Model Fit

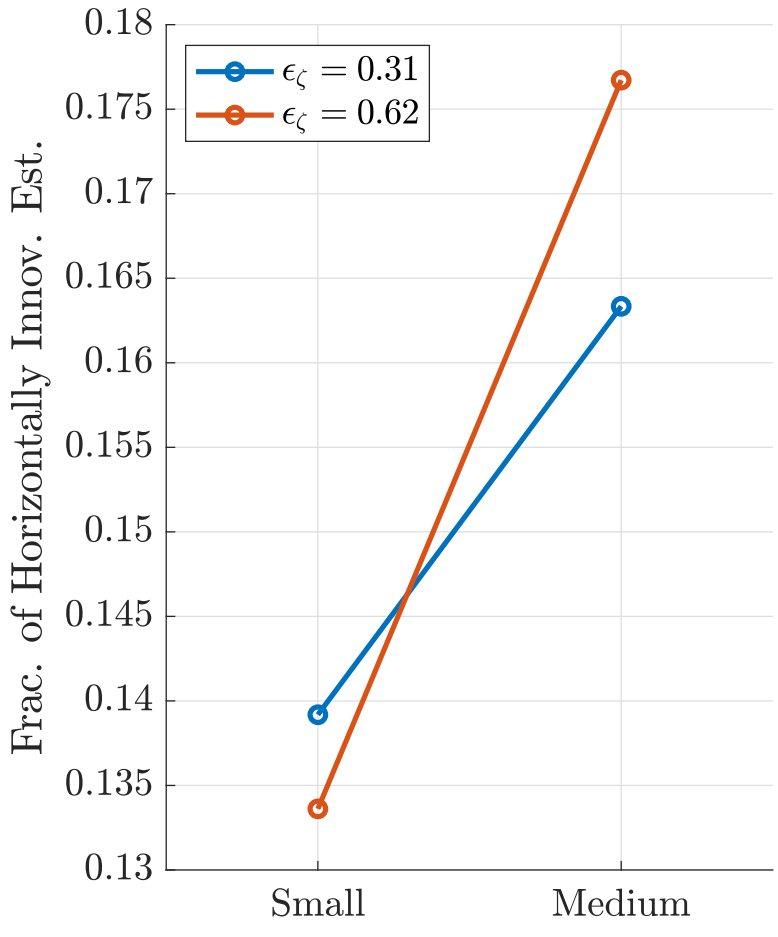
Dynamic Correlation with Innovation



Identification of ϵ_ζ and ϵ_ξ

- A higher elasticity $\Rightarrow$ a steeper size profile of innovation frac.





Structure

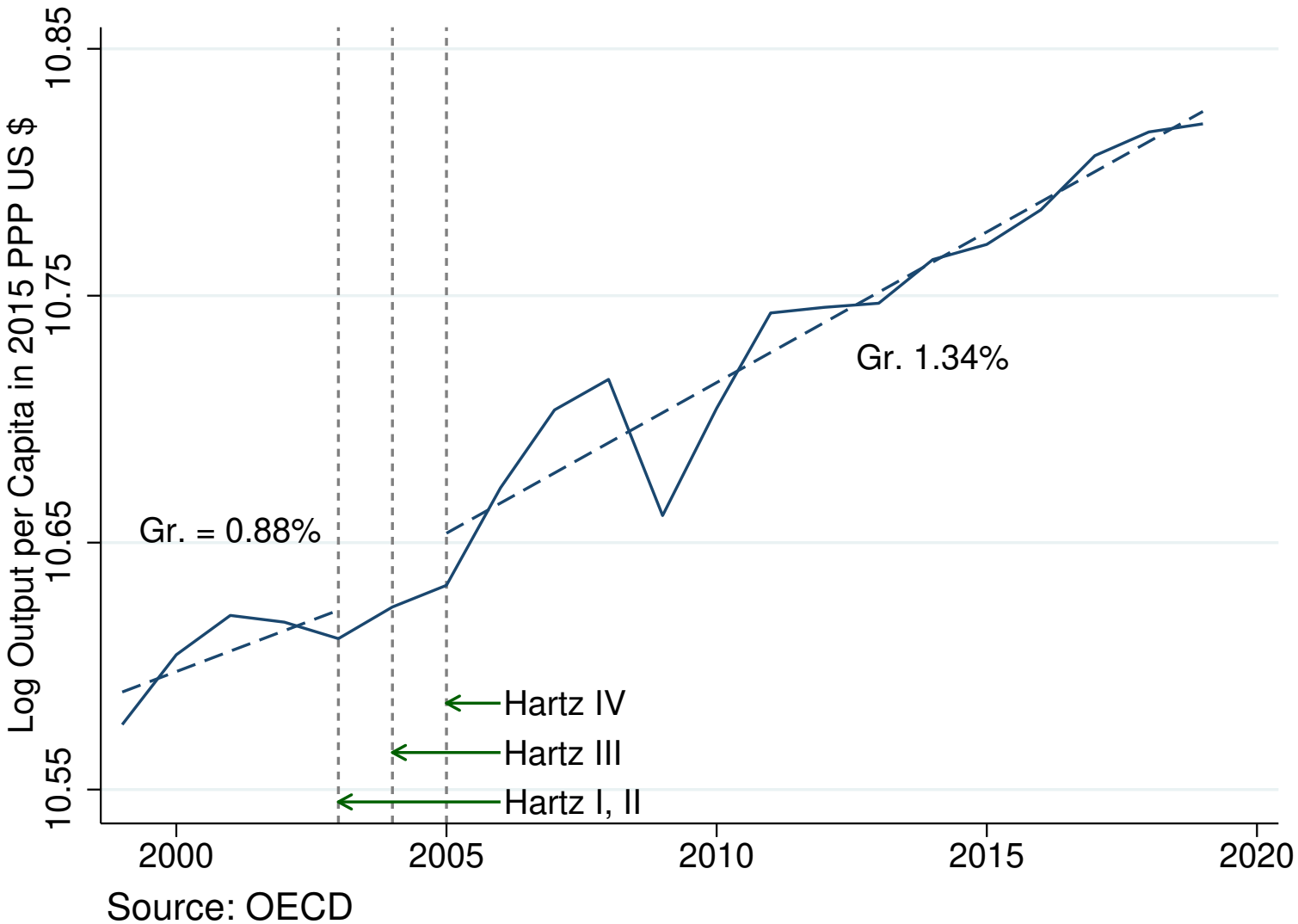
- ★ **New Facts from Survey Measure**
- ★ **Model**
- ★ **Calibration**
- ★ **Counterfactual Analysis**
  - Overview of the Hartz Reform
  - Time series data around the Hartz Reform
  - Counterfactual results

Counterfactual Analysis

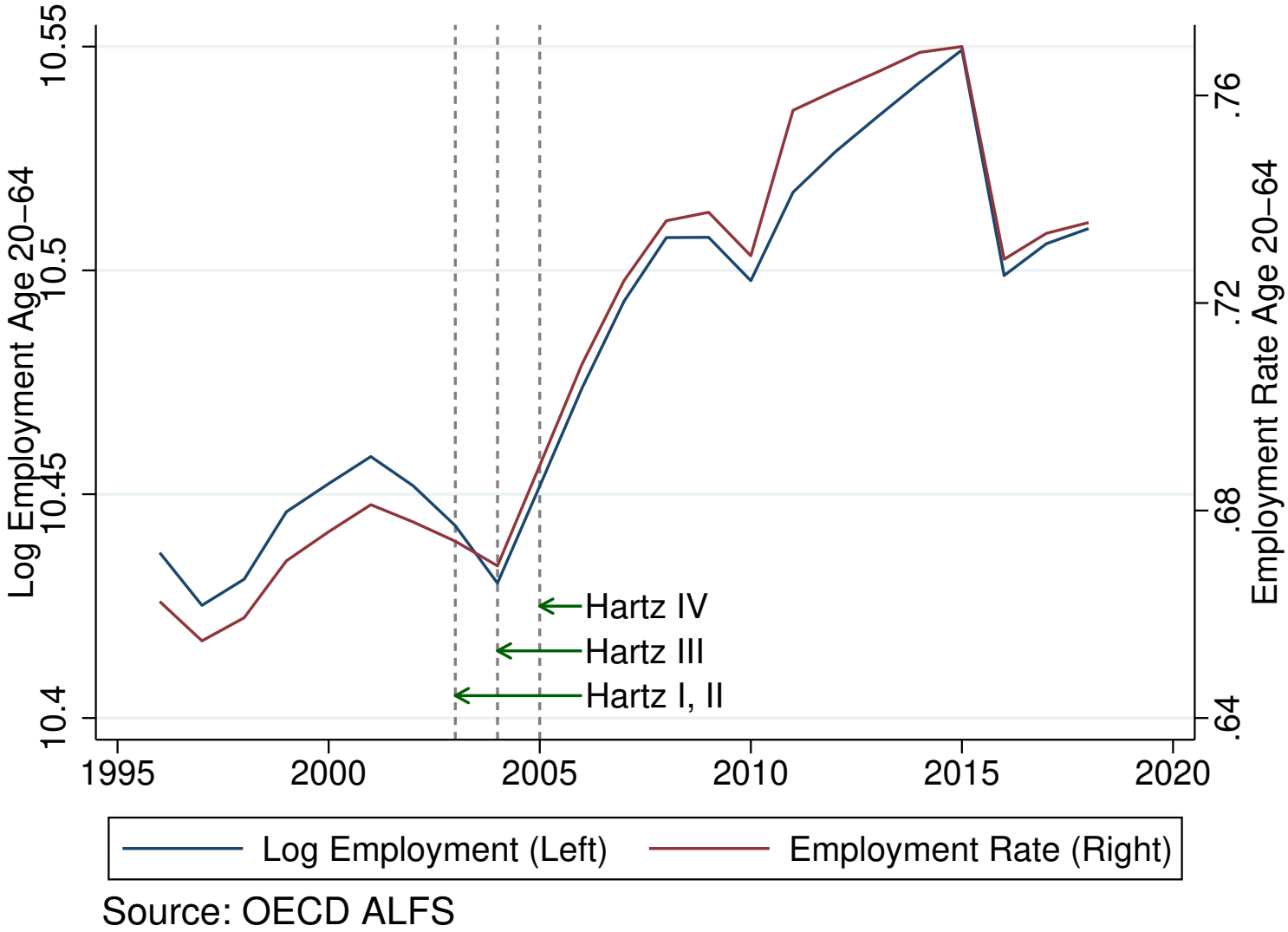
- I focus on the Hartz Reform today.
  - Steady State with and without the policy introduction
    $\Rightarrow$ Impacts on growth and job turnover rates in S-S.
  - Transition from the baseline BGP to the new BGP after the policy introduction
    $\Rightarrow$ Welfare Analysis
- Three Major components of Hartz Reform (Jacobi and Kluve, 2006)
  1. improving employment services and policy measures
  2. activating the unemployed
  3. fostering employment demand by deregulating the labour market

Other Counterfactuals

Labor Market Reform and GDP growth in Germany

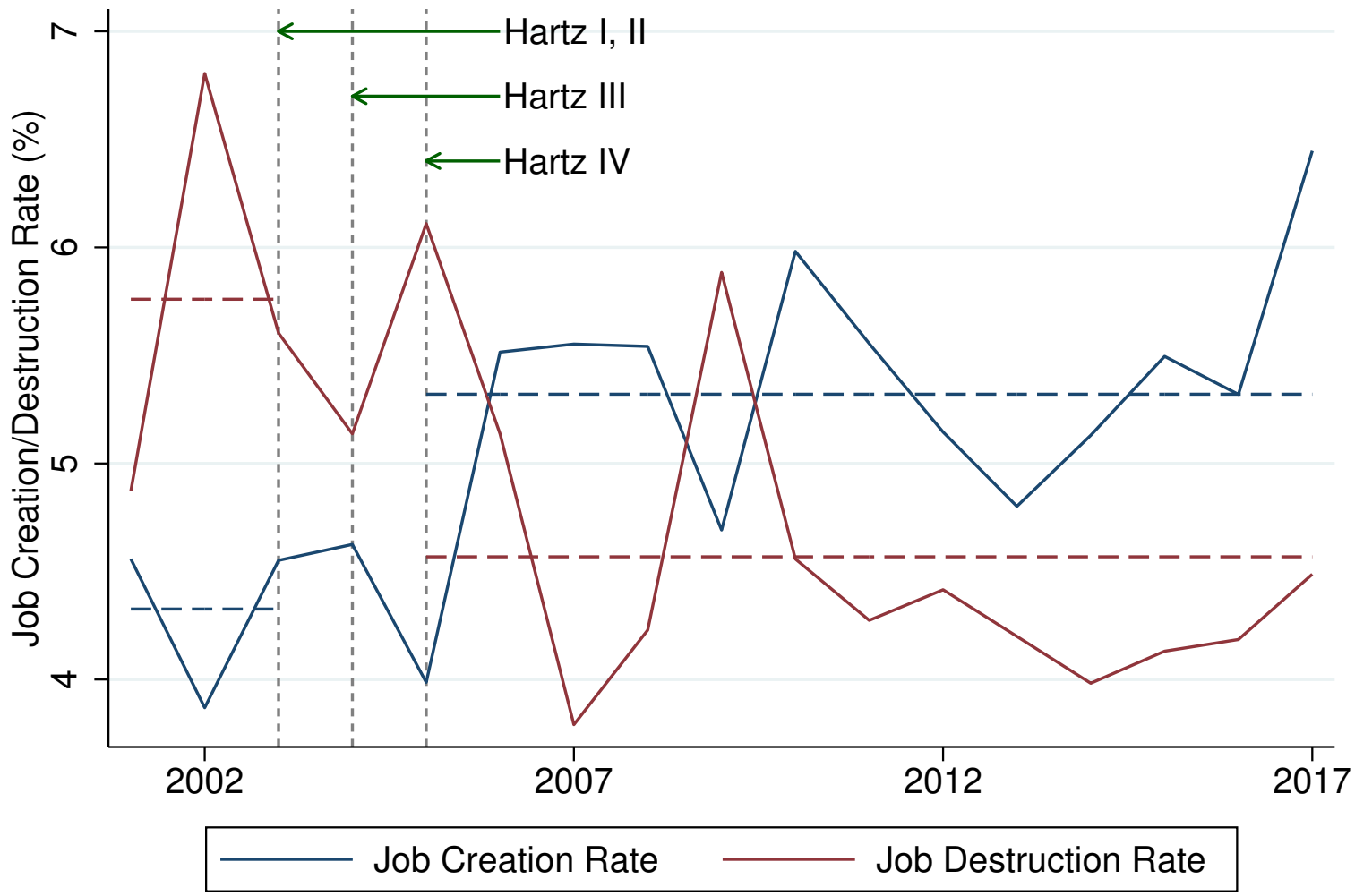


Labor Market Reform and Employment



Source: OECD ALFS

Labor Market Reform and Job Turnover



Source: Author's Calculation from IAB–BP Microdata

The Hartz Reform: Aggregate Moments

- Reduction in labor wedge ω_L and firing cost parameter, κ.
- Changes in labor wedge to match the actual increase in employment.
- Decrease in κ to match the average firing cost.
- Frisch elasticity of labor supply $= 1$, entry elasticity $= 0.1$

Moment	Pre	No Labor Wedge	No Firing Cost	Post
Output Growth Rate	1.23	1.30	1.23	1.30
Wage	1.097	0.999	1.099	1.000
R&D Labor Share	29.2	27.4	29.2	27.4
Job Reallocation	1.73	1.73	1.73	1.73
Vertical Innovation	16.1	16.9	16.1	16.9
Horizontal Innovation	0.52	0.53	0.52	0.53

Note: All in % except Wage. All flow rates are annual.

Alternative Elasticity Values

The Hartz Reform: Decomposition

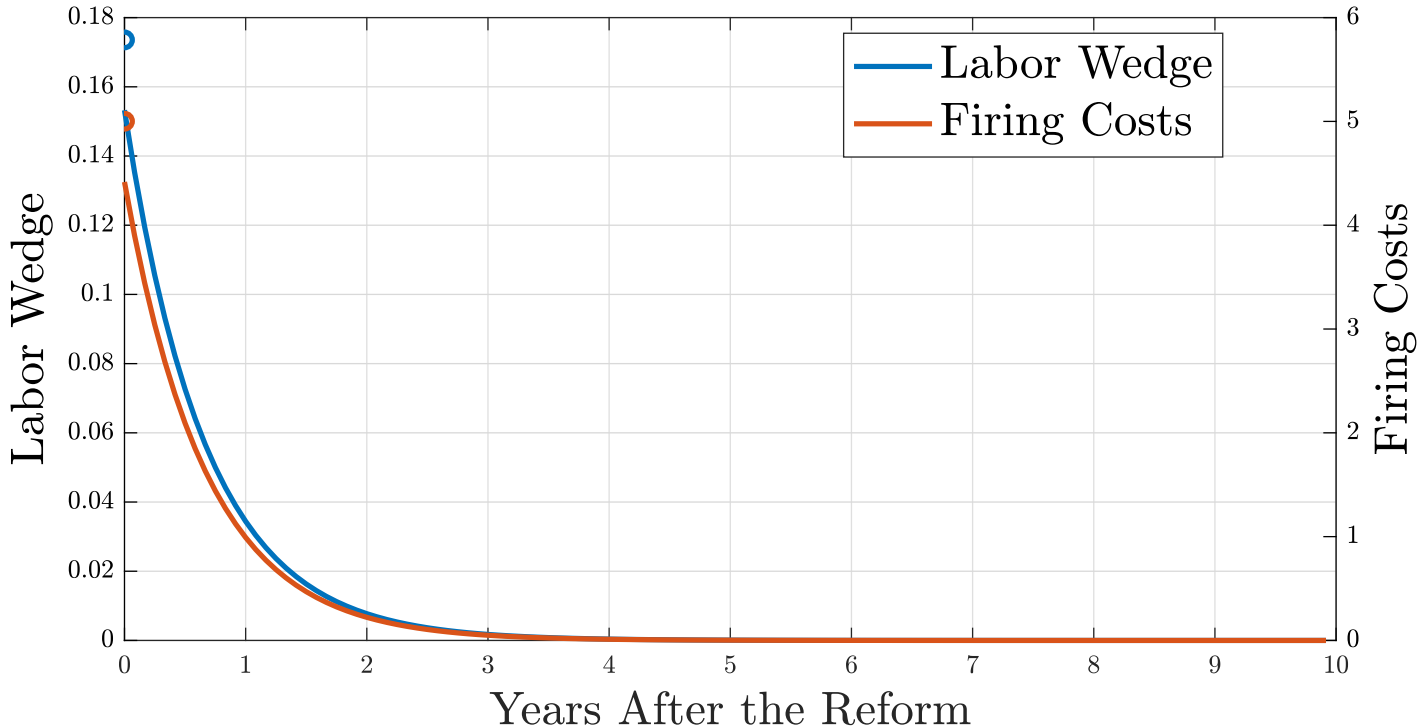
- Almost all growth from vertical innovation.
- However, most job creation from horizontal and entrant innovations.

Moment	Pre	No Labor Wedge	No Firing Cost	Post
Job Creation from Vertical Innovation	25.4	26.2	25.5	26.2
Job Creation from Horizontal Innovation	26.8	26.8	26.8	26.8
Job Creation Due Entrant Innovation	47.8	47.0	47.8	47.0
Job Destruction from Creative Destruction	12.5	13.1	12.5	13.1
Job Destruction from Obsolescence	29.8	29.1	29.8	29.0
Job Destruction from Exit	57.7	57.8	57.7	57.8
Growth from Vertical Innovation	91.3	90.5	91.8	90.8
Growth from Horizontal Innovation	2.6	2.9	2.5	2.8
Growth from Entrant Innovation	6.1	6.7	5.8	6.4

Note: All in %

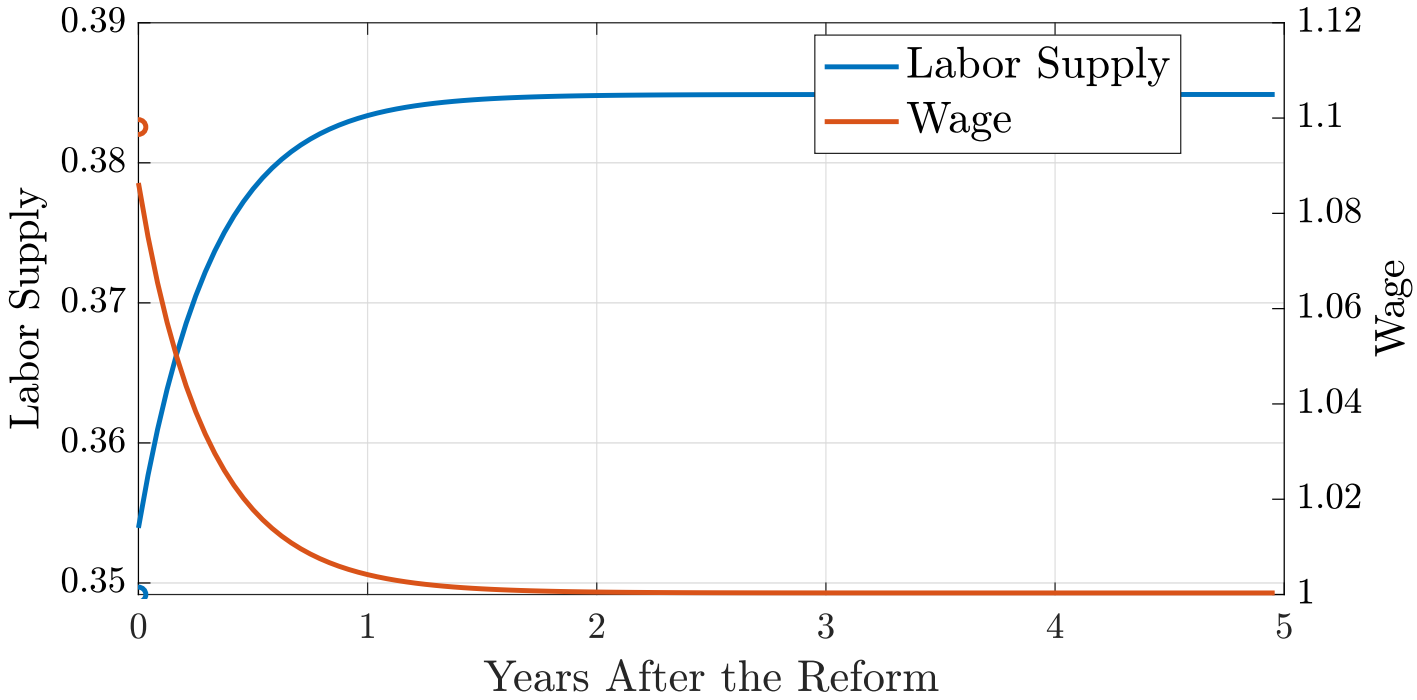
The Hartz Reform: Transition

- Smooth Decrease in ω_L and κ.



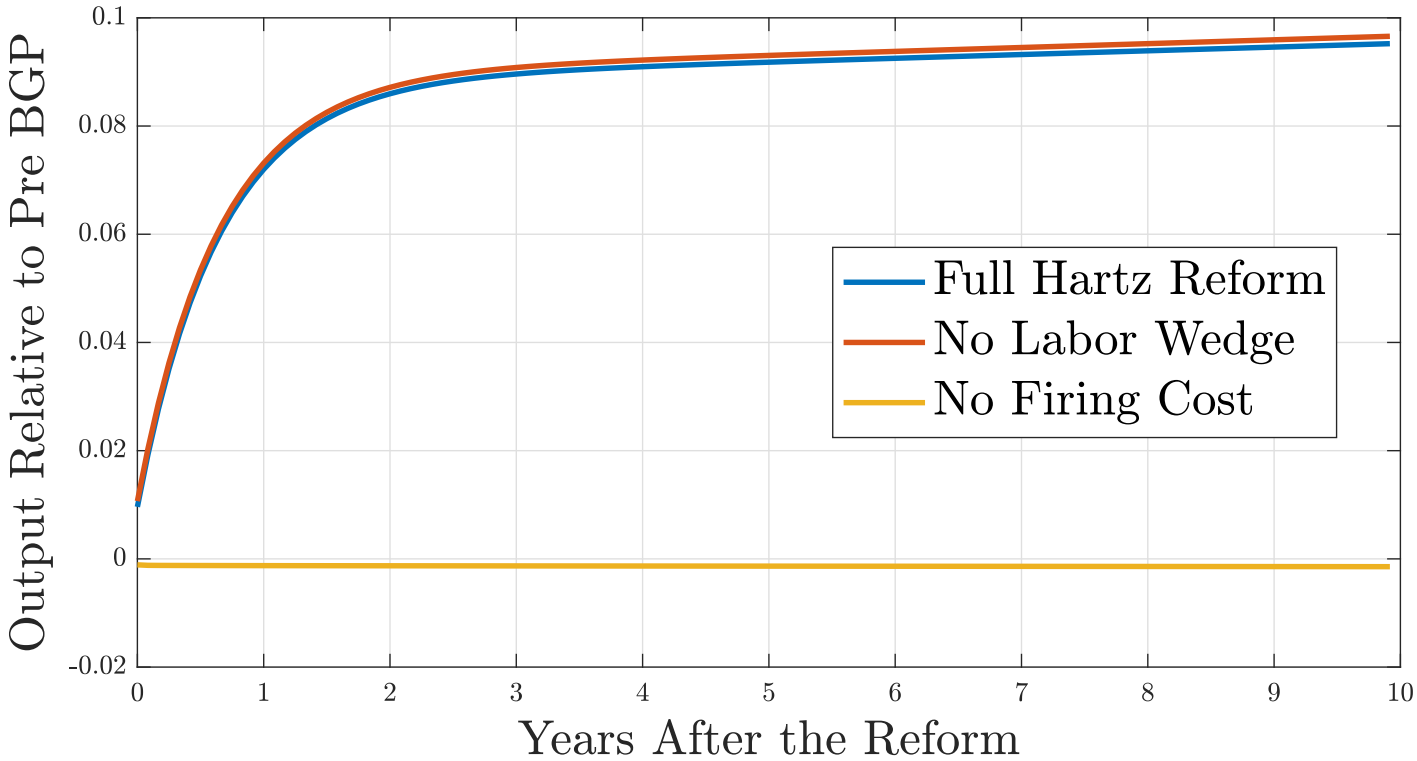
The Hartz Reform: Transition

- Smooth increase/decrease in labor supply/wage.



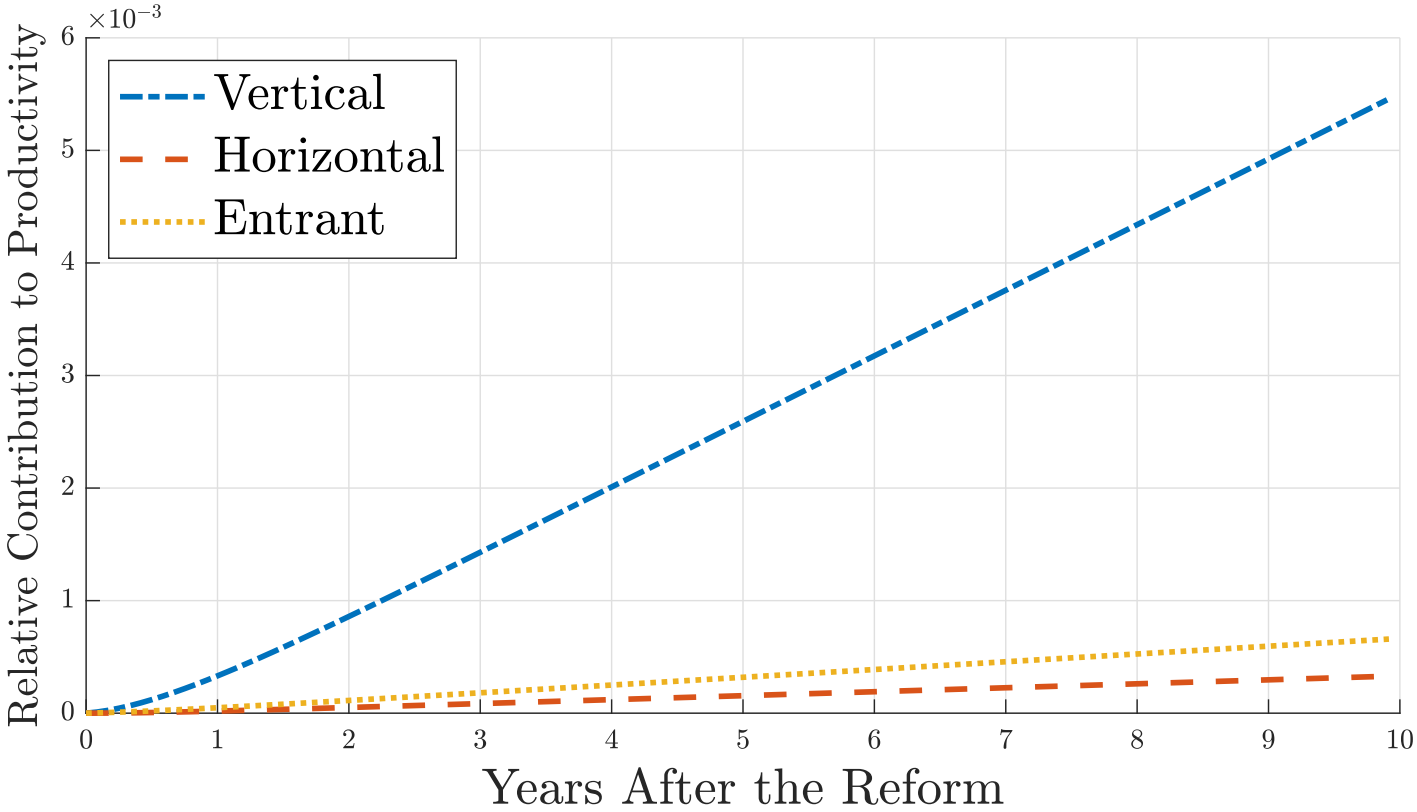
The Hartz Reform: Transition

- The labor supply margin contributes to output growth.



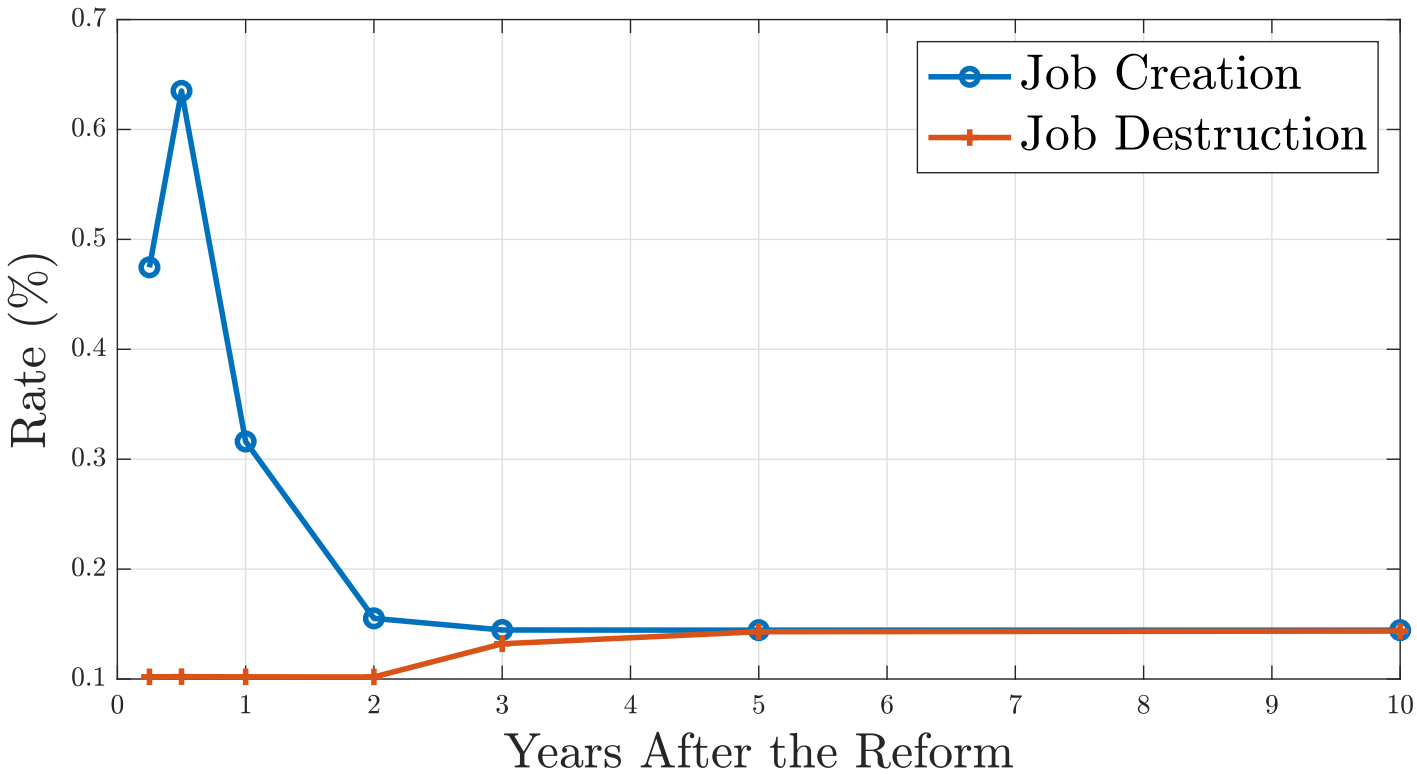
The Hartz Reform: Transition

- Vertical innovation makes a noticeable difference in productivity growth.



The Hartz Reform: Transition

- Job creation $\Uparrow$, but job destruction $\Downarrow$ relative to the pre-reform BGP.



Note: Approximated time interval is 1 month.

The Hartz Reform: Transition

- Additional productivity gr. $= 1\%$ permanent $\Uparrow$ in consumption.
- Vertical innovation $= 85\%$ of all dynamic gains.

	No Labor Wedge	No Firing Cost	Post
Consumption Equivalent Variation	6.05	-0.18	5.87
Initial Output Change	1.07	-0.11	0.97
Vertical Innovation	0.80	0.05	0.83
Horizontal Innovation	0.06	-0.02	0.05
Entrant Innovation	0.15	-0.06	0.10
Labor Supply	-3.22	-0.04	-3.27

Note: All in %

Concluding Remarks

- A new survey-based measure of innovation for economic analysis.
- A quantitative quality ladder model.
  - Horizontal innovation generates more job flows.
  - However, vertical innovation accounts for most of economic growth.
- Aggregate implications of a labor market reform in Germany.
  - Additional productivity growth comes mostly from vertical innovation.

  $\Rightarrow$ Faster productivity growth but no increases in job destruction rates.

★ Labor reallocation not crucial for long-run growth.
  - Even more so under labor adjustment costs and learning-by-doing.

Appendix

Variables in IAB-BP

- Establishments are asked whether they implemented the following innovation activities in the previous year.
  - Process innovation: improve the production process
  - Quality improvement: improve the products they previously produced
  - Product expansion: start to offer a product that previously existed in the market
  - Variety creation: start to offer a product that did not exist in the market
- Vertical innovation includes process innovation and quality improvement while horizontal innovation includes product expansion.

Variables in IAB-BP

- Establishments are asked whether they implemented the following innovation activities in the previous year.

Table: Raw Innovation Frequencies across Size (in %)

	Quality Improv.	Product Expansion	New Variety	Process Innov.	Any Innov.	N. Est.
All	31.01	20.09	5.76	11.77	39.70	91,823
Small	23.01	14.82	3.36	7.09	30.72	10,363
Medium	27.18	16.80	3.80	9.20	34.78	11,263
Large	38.60	23.56	7.95	16.61	47.94	42,670

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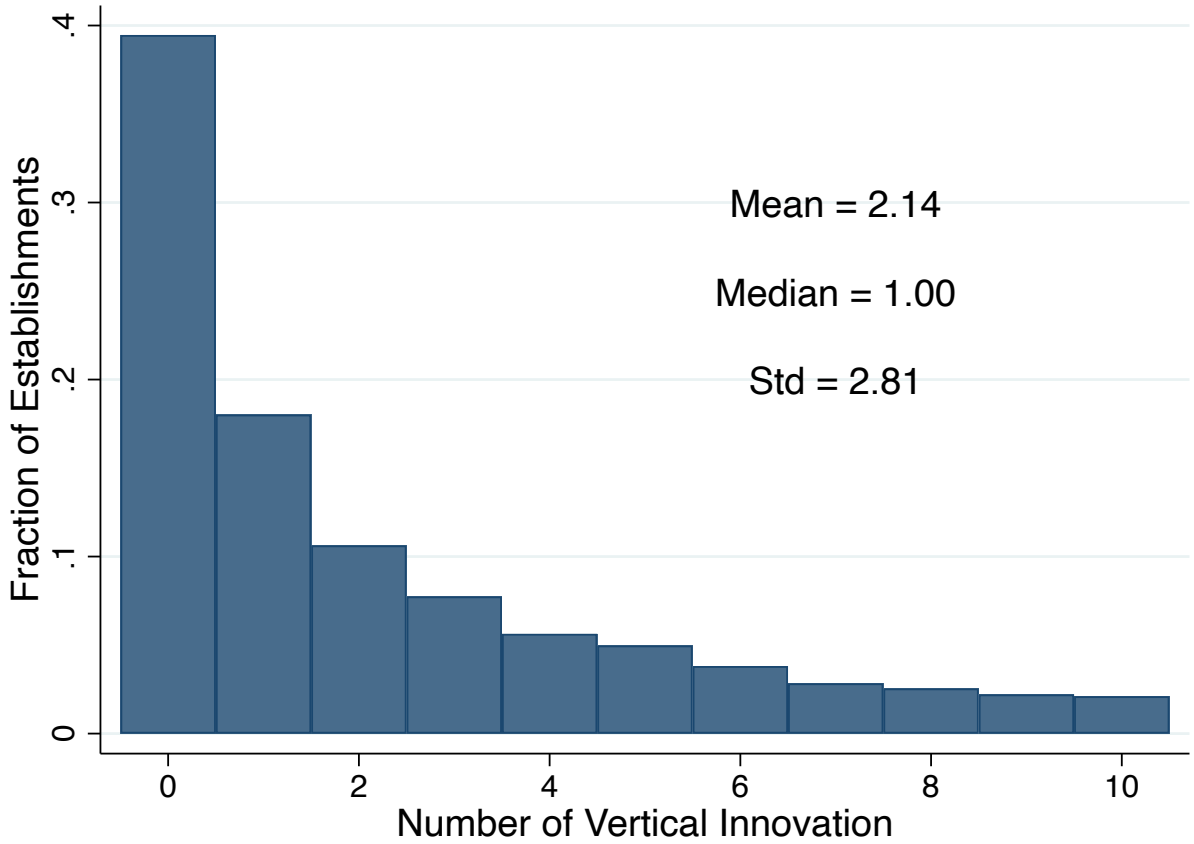
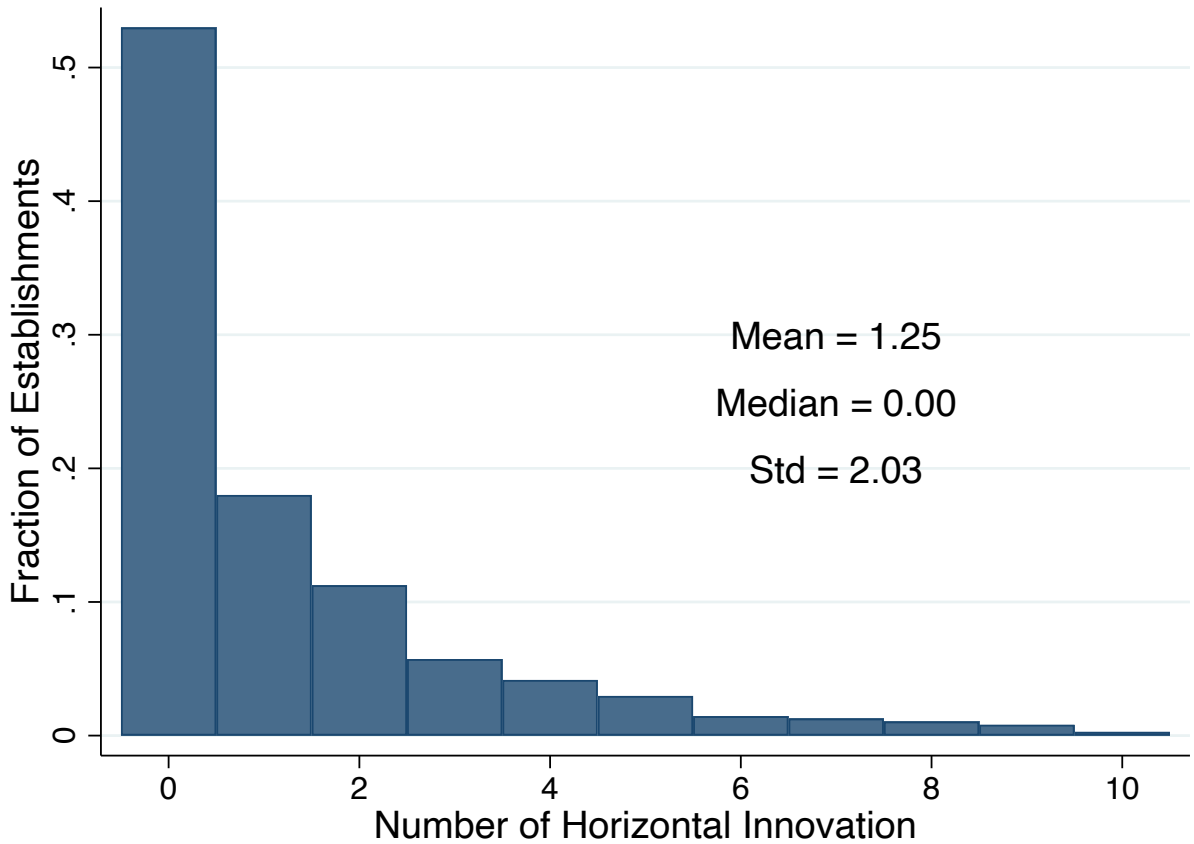
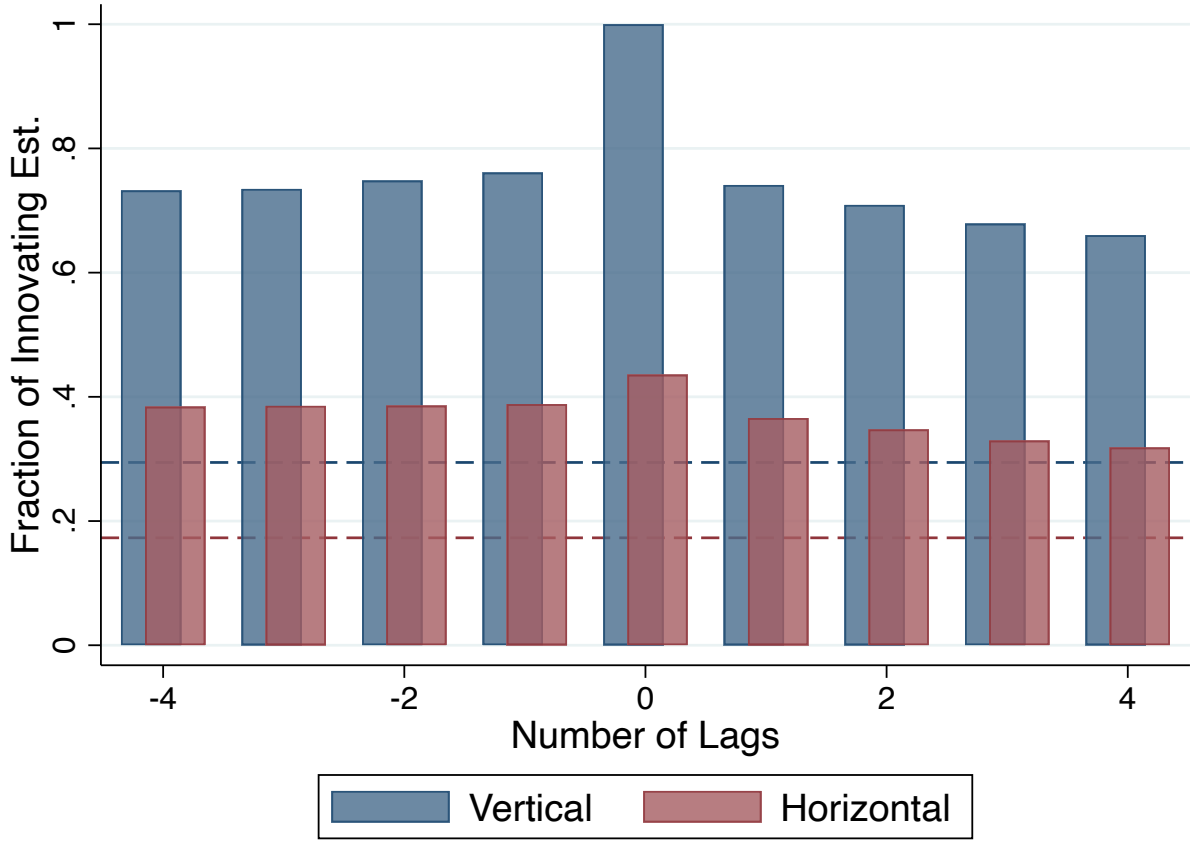
Distribution of Innovation Events across Est.



Distribution of Innovation Events across Est.



Autocorrelation of Innovation



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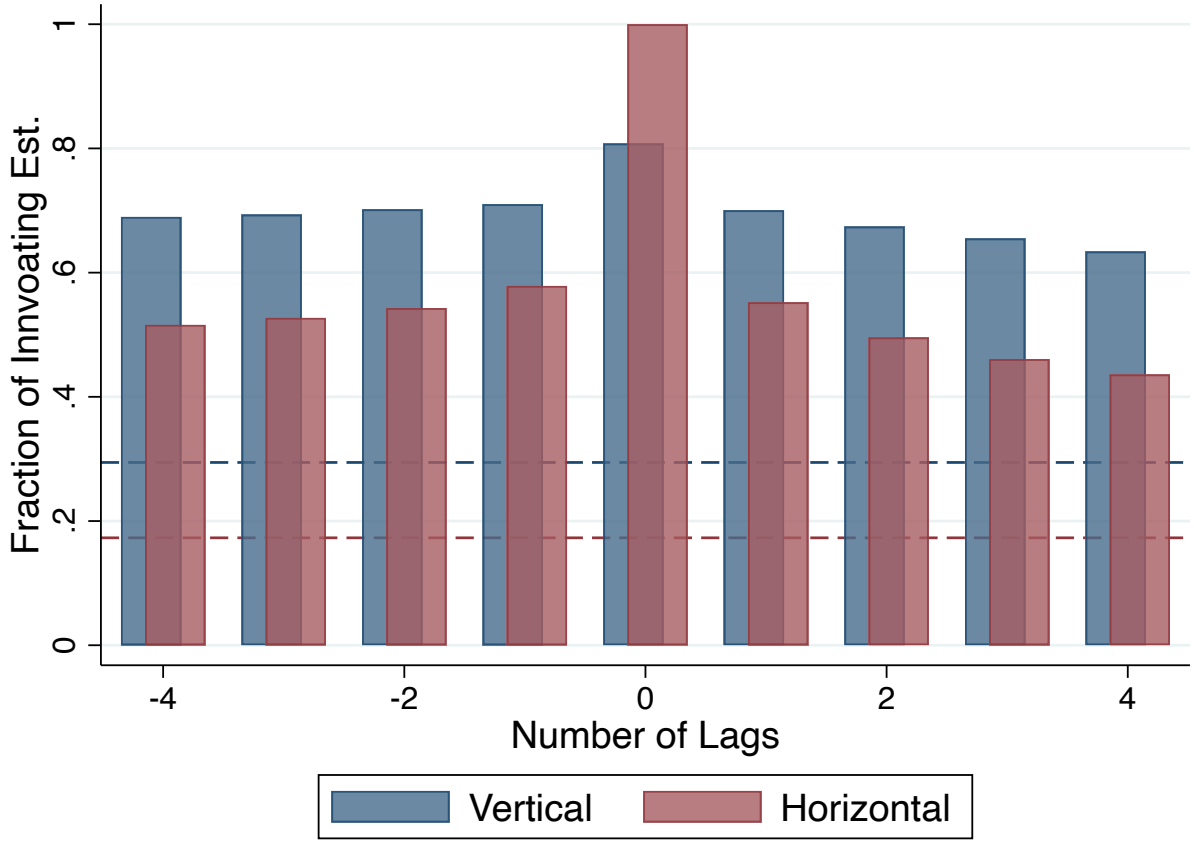
Autocorrelation of Innovation



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Definitions of Outcome Variables

- The survey has information on extensive establishment-level variables
  - Employment as of June 30, # of hiring in the fist half of the year, # of separation in the first half of the year, Labor expenses as of June, Investment last year, Business volume last year, # of training participation in the first half of the year
- Definitions of Outcome Variables
  - Employment growth = $(AdmEmp - L.AdmEmp)/(\frac{1}{2}AdmEmp + \frac{1}{2}L.AdmEmp)$
  - Wage, Revenue, Investment growth rates are defined similarly.
  - Hiring rate = $2 \times Hiring/(\frac{1}{2}AdmEmp + \frac{1}{2}L.AdmEmp)$
  - Separation rate = $2 \times Separation/(\frac{1}{2}AdmEmp + \frac{1}{2}L.AdmEmp)$
  - Training Rate = $2 \times \#ClassParticipation/(\frac{1}{2}AdmEmp + \frac{1}{2}L.AdmEmp)$
  - Establishment age = Survey Year - Year of Foundation

Definitions of Outcome Variables - Continued

- The variables are further defined by the following.
  - $AdmEmp$ = Employment of an establishment as of June 30 in the survey year from the administrative data
  - $Hiring$ = Total number of newly hired workers in the first half of the survey year from the survey
  - $Separataion$ = Total number of separated workers in the first half of the survey year from the survey
  - $Wage$ = Imputed mean daily wage as of June in the survey year from the administrative data
  - $Revenue$ = Business volume in the previous year from the survey
  - $Investment$ = Sum of investment expenditures in the previous year from the survey
  - $\#ClassParticipation$ = Total number of participants or cases of participation in internal or external training courses the establishments cover the expenses in full or in part

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Summary Statistics for Outcome Variables

- All results are weighted by cross-sectional weights.

Table: Summary Statistics - Outcome Variables (in %)

	Mean	Sd	Median	1st Q.	3rd Q.	N.
Employment Gr.	0.72	22.06	0.00	0.00	4.88	110,946
Hiring Rate	13.77	40.56	0.00	0.00	10.53	99,046
Separation Rate	11.39	36.18	0.00	0.00	6.30	99,112
Wage Gr.	2.14	14.65	1.27	-1.52	5.93	91,358
Rev. Gr.	2.13	27.86	0.00	-7.68	12.39	77,919
Invest. Gr.	-5.63	1.55	0.00	-198.01	169.23	81,008
Training Rate	79.73	184.23	24.29	0.00	131.58	85,546

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Dynamic Correlation - Specification

- Variables of interest, Y_{it}:
  - Employment growth rate $= (Emp - L.Emp)/(\frac{1}{2}Emp + \frac{1}{2}L.Emp)$
  - Wage growth rate $= (Wage - L.Wage)/(\frac{1}{2}Wage + \frac{1}{2}L.Wage)$
  - Employment and wage variables come from the administrative data.

Other Variables Descriptive Statistics

- Consider the following dynamic correlation model.

$$Y_{it} = \sum_{s=-5}^{5} \mathbf{1}_{it+s}^{a} \beta_s^a + \gamma' X_{it} + \varepsilon_{it}$$

where $\mathbf{1}_{it}^{a}$ is indicator of innovation type a = vertical or horizontal.

- Controls: Other types of innovation, establishment and year f.e..

! Entrant/exiting firms are excluded.

Innovation and Non-Innovating Establishments

- The panel regression specification, $j(i)$ for sector and t for year

$$Y_{it} = \beta^V L.V_{j(i)t} + \beta^H L.H_{j(i)t} + \gamma' X_{it} + \epsilon_{it},$$

Controls include fixed effects, lagged size, HHI, industrial emp. growth.

	Emp. Gr.	Exit	Wage Gr.	Emp. Gr.	Exit	Wage Gr.
$V_{j(i)t}$	1.45	0.49	-0.37	3.34	1.21	1.04
	(2.88)	(1.78)	(1.71)	(2.92)	(1.82)	(1.74)
$H_{j(i)t}$	-10.06***	6.10***	5.89***	-10.85***	5.49***	5.24***
	(2.88)	(1.78)	(1.71)	(2.92)	(1.82)	(1.74)
$E_{j(i)t}$				-38.85**	33.97***	-23.52**
				(19.11)	(11.91)	(11.82)
N.	20,997	21,921	18,024	20,997	21,149	18,024
F.E.	Year	Year	Year	Year	Year	Year
Ind. Ctr.	No	No	No	Yes	Yes	Yes

- Horizontal innov. has stronger impact on job turnover than vertical innov.

Regression Results - Employment Growth

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, $a =$ vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	1.05^{***}		0.85^{***}	-0.34		-0.93
	(0.31)		(0.32)	(0.67)		(0.75)
Horizontal Innov.		1.23^{***}	1.10^{***}		2.42^{***}	3.25^{***}
		(0.35)	(0.38)		(0.83)	(0.97)
N.	100,770	100,770	100,770	100,770	100,770	100,770
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

Regression Results - Hiring Rate

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, $a =$ vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	1.98^{***}		1.26^{**}	2.33^{*}		0.97
	(0.59)		(0.62)	(1.28)		(1.44)
Horizontal Innov.		2.75^{***}	2.41^{***}		3.80^{**}	3.34^{*}
		(0.68)	(0.73)		(1.60)	(1.86)
N.	100,406	100,406	100,406	100,406	100,406	100,406
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

Regression Results - Separation Rate

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, a = vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	0.56		0.28	2.96**		2.61*
	(0.59)		(0.62)	(1.28)		(1.45)
Horizontal Innov.		0.76	0.62		1.28	-0.09
		(0.68)	(0.73)		(1.60)	(1.86)
N.	100,475	100,475	100,475	100,475	100,475	100,475
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

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Regression Results - Wage Growth

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, $a =$ vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	0.60***		0.65***	-0.79**		-0.89**
	(0.17)		(0.18)	(0.37)		(0.41)
Horizontal Innov.		-0.10	-0.31		-0.18	0.05
		(0.20)	(0.21)		(0.46)	(0.53)
N.	91,482	91,482	91,482	91,482	91,482	91,482
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

Regression Results - Revenue Growth

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, a = vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	1.33***		0.98**	-2.34***		-2.70***
	(0.36)		(0.38)	(0.78)		(0.87)
Horizontal Innov.		1.27***	0.86**		0.36	1.12
		(0.41)	(0.44)		(0.97)	(1.12)
N.	71,318	71,318	71,318	71,318	71,318	71,318
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

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Regression Results - Investment Growth

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, $a =$ vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	29.06^{***}		24.88^{***}	12.37^{***}		8.49^{*}
	(2.09)		(2.20)	(4.53)		(5.09)
Horizontal Innov.		25.00^{***}	15.64^{***}		18.51^{***}	12.77^{*}
		(2.38)	(2.55)		(5.66)	(6.54)
N.	73,851	73,851	73,851	73,851	73,851	73,851
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

Regression Results - Training Rate

- 1 Year - β_0^a, 4 Year - $\sum_{s=0}^{3} \beta_s^a$, a = vertical or horizontal.

N. Lags	1 Year	1 Year	1 Year	4 Years	4 Years	4 Years
Vertical Innov.	26.89***		15.92*	36.22**		-0.37
	(7.88)		(8.36)	(18.21)		(20.66)
Horizontal Innov.		37.80***	27.49***		74.46***	48.87*
		(9.03)	(9.78)		(22.71)	(26.56)
N.	86,869	86,869	86,869	86,869	86,869	86,869
Other Innov.			✓			✓
Fixed Effects	Est.	Est.	Est.	Est.	Est.	Est.

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Industry-level Innovation and Non-Innovating Establishments

- The panel regression specification, $j(i)$ for sector and t for year

$$Y_{it} = \beta^V L.V_{j(i)t} + \beta^H L.H_{j(i)t} + \gamma' X_{it} + \epsilon_{it},$$

Controls include fixed effects, lagged size, HHI, industrial emp. growth.

	Dep. Variable: Employment Growth					
	(1)	(2)	(3)	(4)	(5)	(6)
Vertical Innov.	-2.03		3.34	-24.17***		-17.35
	(2.57)		(2.92)	(8.89)		(9.28)
Horizontal Innov.		-9.34***	-10.85***		-32.05***	-29.51***
		(2.57)	(2.92)		(9.60)	(10.13)
Entrant Emp. Share			-38.85**			-53.71
			(19.11)			(30.03)
N.	20,997	20,997	20,997	20,839	20,839	20,839
Fixed Effects	Year	Year	Year	Year & Sector	Year & Sector	Year & Sector

Go back

Industry-level Innovation and Non-Innovating Establishments

- The panel regression specification, $j(i)$ for sector and t for year

$$Y_{it} = \beta^V L.V_{j(i)t} + \beta^H L.H_{j(i)t} + \gamma' X_{it} + \epsilon_{it},$$

Controls include fixed effects, lagged size, HHI, industrial emp. growth.

	Dep. Variable: Establishment Exit					
	(1)	(2)	(3)	(4)	(5)	(6)
Vertical Innov.	4.00**		1.21	6.11		9.66
	(1.60)		(1.82)	(5.44)		(5.68)
Horizontal Innov.		6.15***	5.49***		-10.34	-12.79**
		(1.60)	(1.82)		(5.89)	(6.21)
Entrant Emp. Share			33.97***			10.06
			(11.91)			(18.41)
N.	21,149	21,149	21,149	20,989	20,989	20,989
Fixed Effects	Year	Year	Year	Year & Sector	Year & Sector	Year & Sector

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Industry-level Innovation and Non-Innovating Establishments

- The panel regression specification, $j(i)$ for sector and t for year

$$Y_{it} = \beta^V L.V_{j(i)t} + \beta^H L.H_{j(i)t} + \gamma' X_{it} + \epsilon_{it},$$

Controls include fixed effects, lagged size, HHI, industrial emp. growth.

	Dep. Variable: Wage Growth					
	(1)	(2)	(3)	(4)	(5)	(6)
Vertical Innov.	3.64**		1.04	4.87		1.71
	(1.44)		(1.69)	(5.18)		(5.40)
Horizontal Innov.		5.81***	5.24***		11.97**	9.75
		(1.48)	(1.74)		(5.62)	(5.93)
Entrant Emp. Share			-23.52**			-32.68
			(11.82)			(17.87)
N.	18,024	18,024	18,024	17,878	17,878	17,878
Fixed Effects	Year	Year	Year	Year & Sector	Year & Sector	Year & Sector

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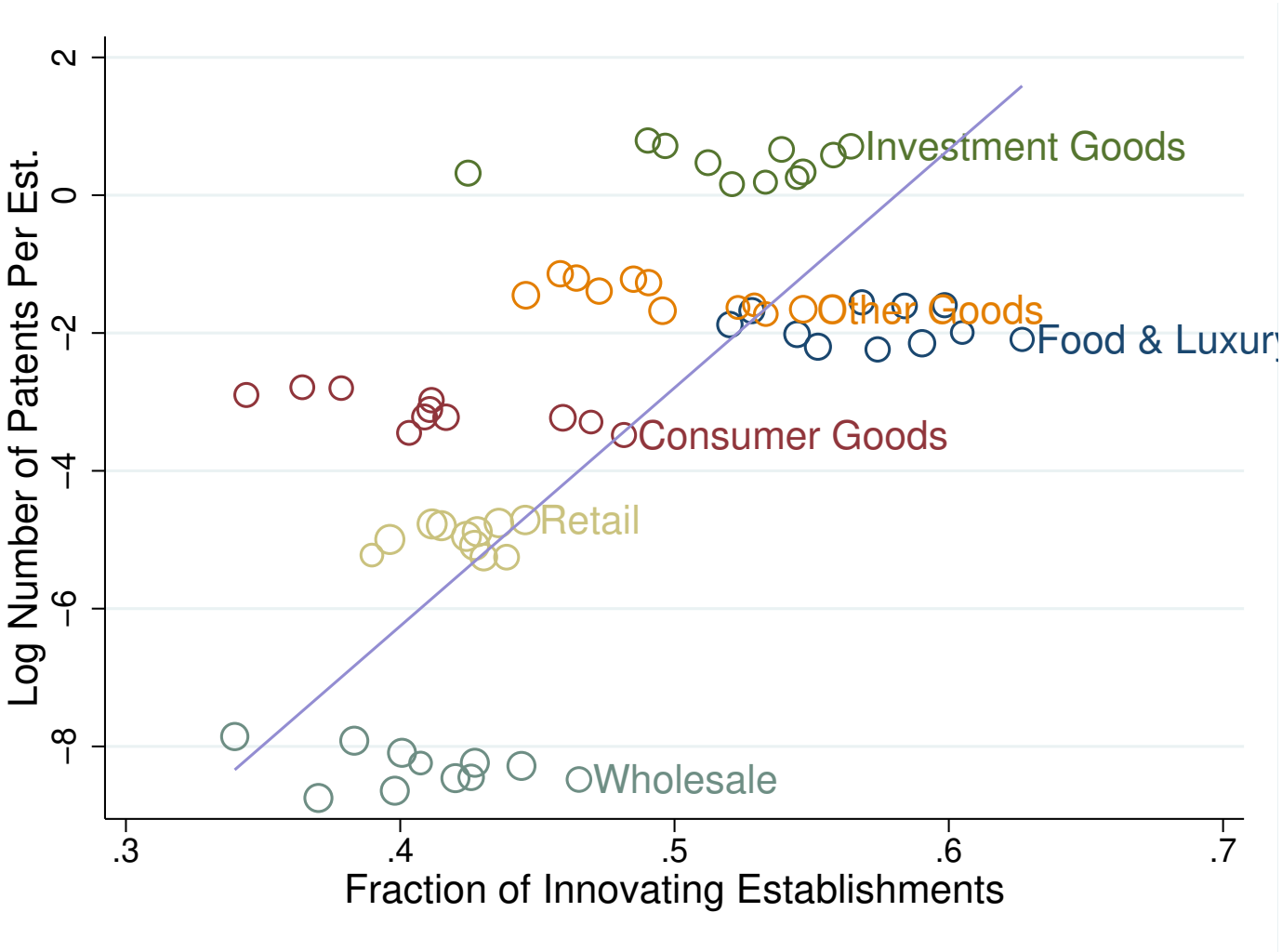
Comparison between Survey and Patent Measures of Innovation

- Construct industry-year level innovation measures using the number of patents granted to German entities.
- Distinction between internal vs. external innovation (Akcigit and Kerr, 2018)
  - **Internal Innovation**: self-citation share ≥ 0.5
  - **External Innovation**: self-citation share < 0.5
- The number of patents does not even exist for agriculture, mining, construction, and service industries.
- Overall survey-based fraction of innovating establishments are strongly positively correlated with the number of patents across different industries and years.

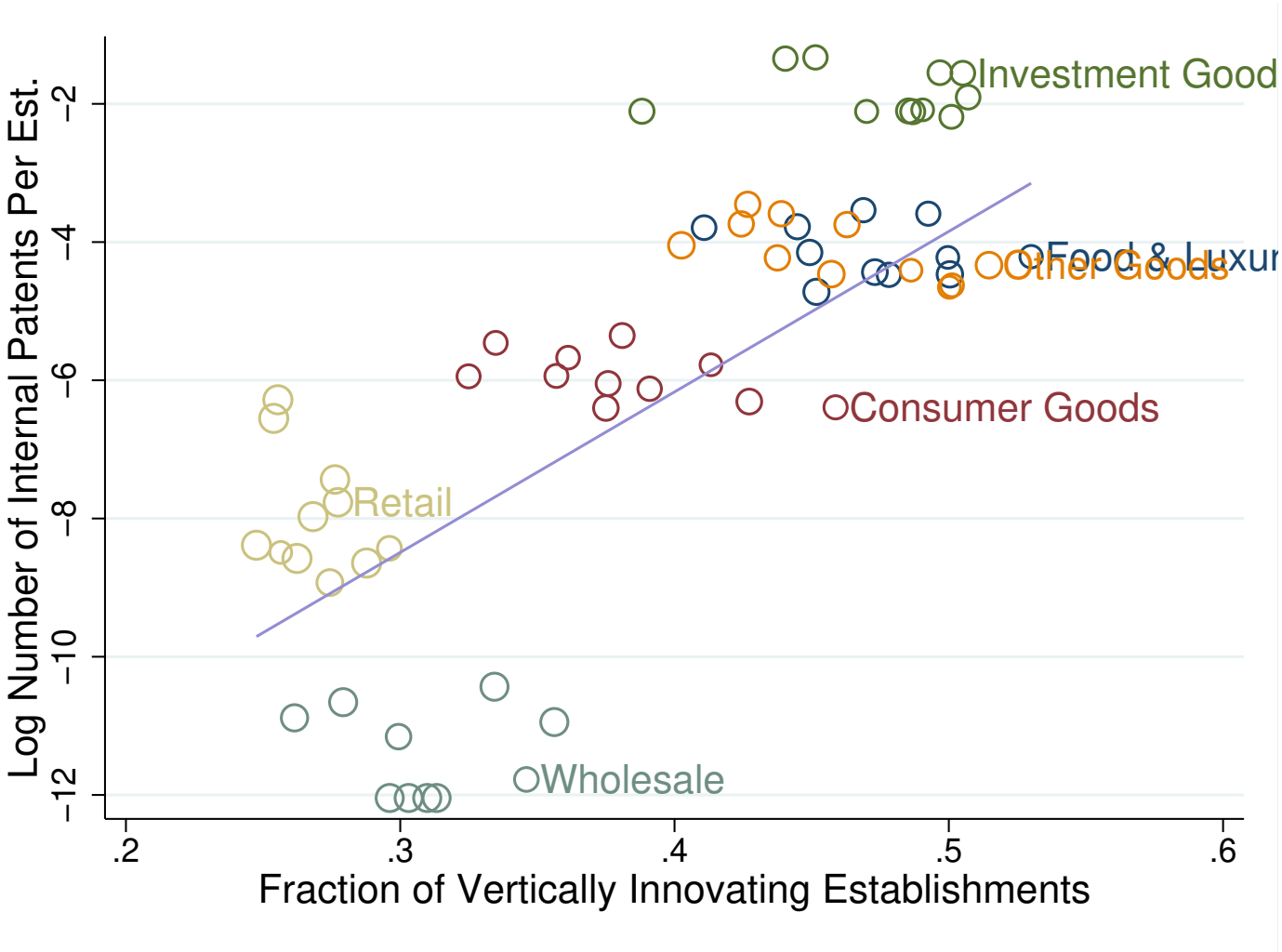
Overall Innovation

- Fraction of either vertically or horizontally innovating establishments vs. the total number of patents



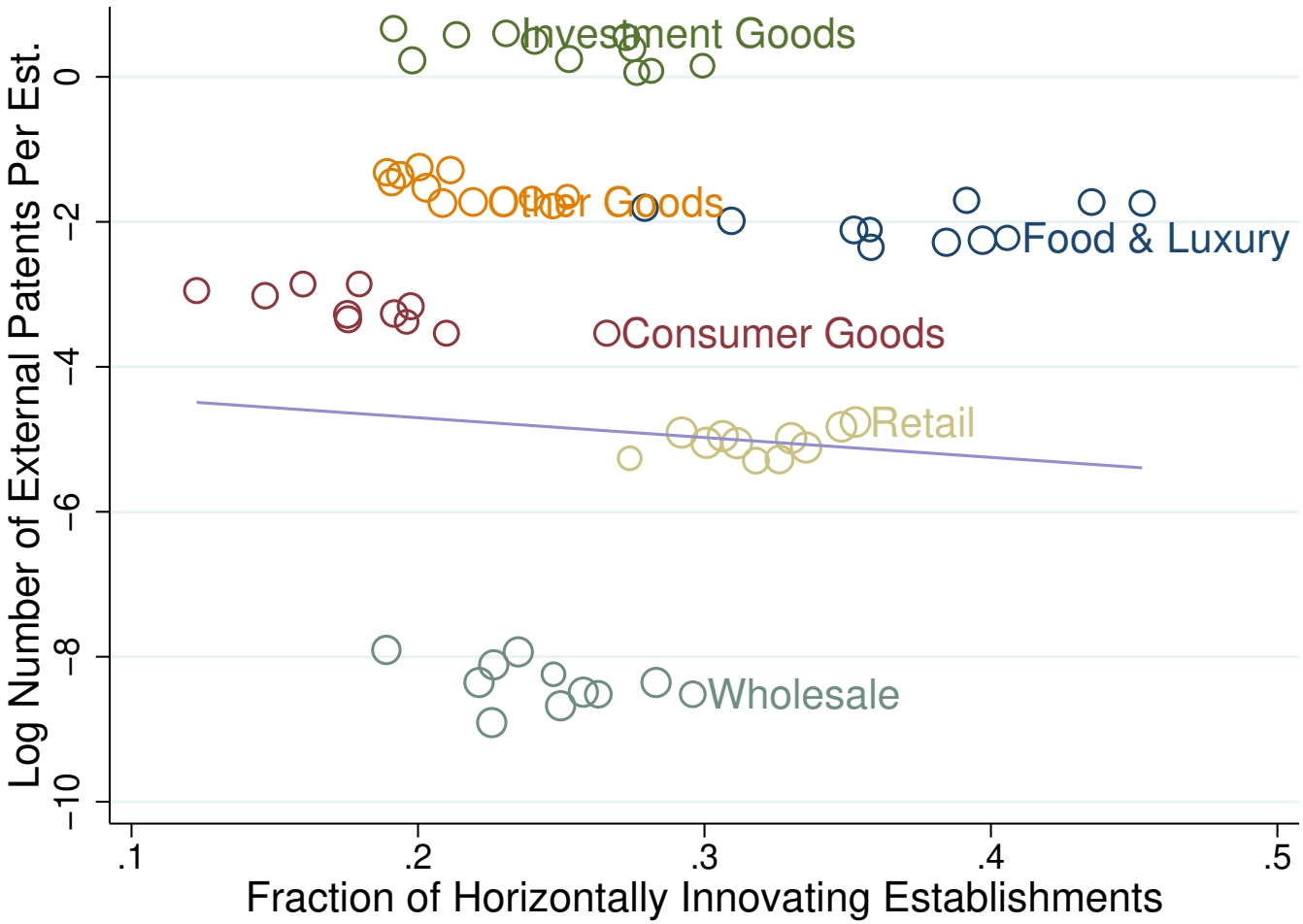
Vertical Innovation vs. Internal Innovation

- Fraction of vertically innovating establishments vs. the total number of internal patents

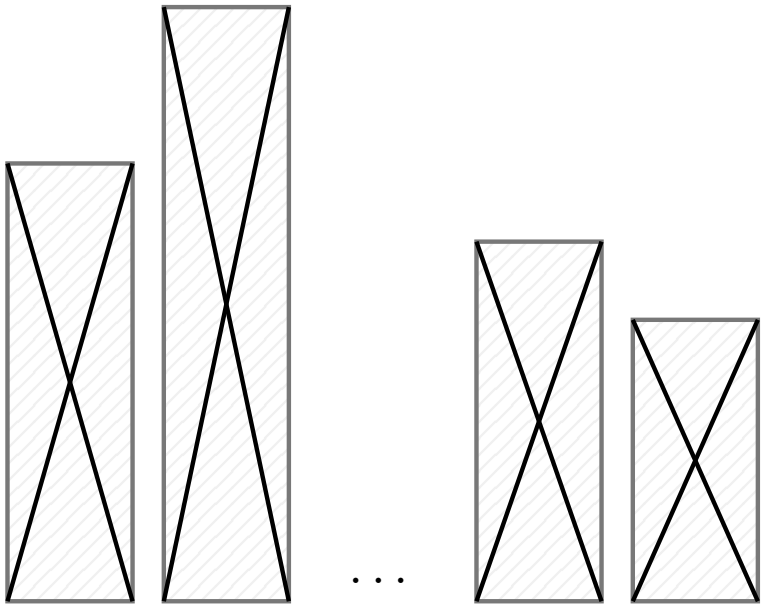


Horizontal Innovation vs. External Innovation

- Fraction of horizontally innovating establishments vs. the total number of external patents



Graphics: Firm Exit

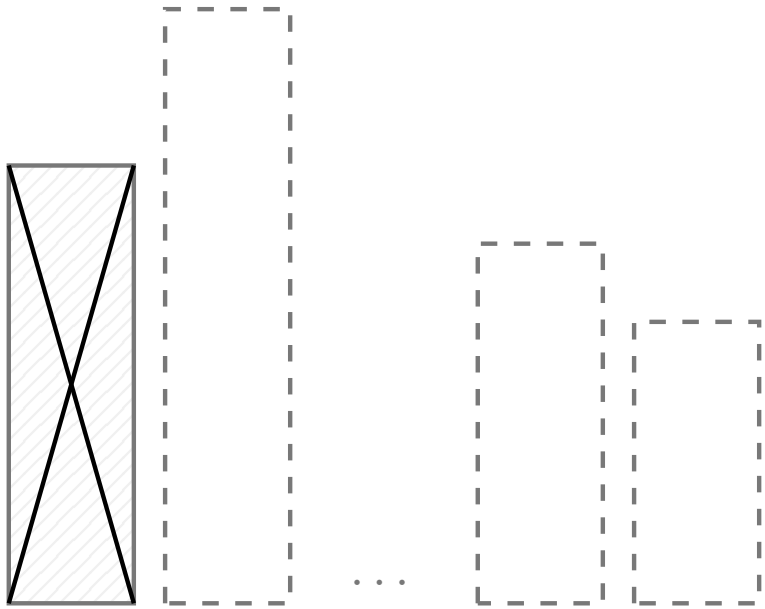


- A firm exits the market in two cases.
  1. Exogenously with rate δ.

  $\Rightarrow$ Product lines held by exiting firms are reallocated toward expanding & entering firms.

  2. The firm loses the last product line by creative destruction.

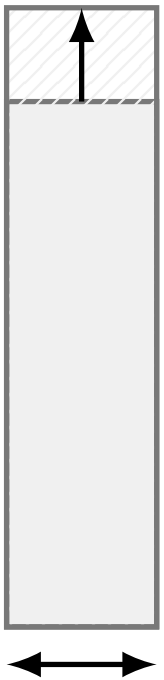
Graphics: Firm Exit



- A firm exits the market in two cases.
  1. Exogenously with rate δ.

  $\Rightarrow$ Product lines held by exiting firms are reallocated toward expanding & entering firms.
  2. The firm loses the last product line by creative destruction.

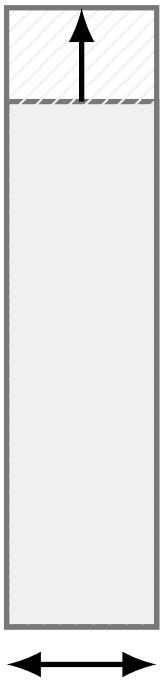
Graphics: Firm Entry



$$\Delta x = \lambda^e \bar{x}$$

- An entering firm is undirectedly matched to a product line to learn and makes vertical innovation with a constant step size $\lambda^e \bar{x}$.
- With probability p, it is matched to a vacant product line.

Graphics: Firm Entry

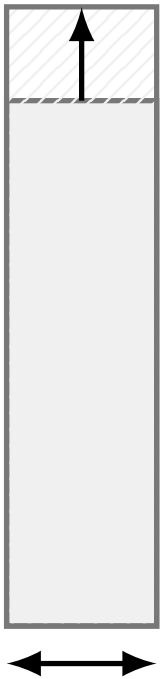


$$\Delta x = \lambda^e \bar{x}$$

- An entering firm is undirectedly matched to a product line to learn and makes vertical innovation with a constant step size $\lambda^e \bar{x}$.
- With probability p, it is matched to a vacant product line.

Go back

Graphics: Firm Entry



$$\Delta x = \lambda^e \bar{x}$$

- An entering firm is undirectedly matched to a product line to learn and makes vertical innovation with a constant step size $\lambda^e \bar{x}$.
- With probability $1 - p$, it is matched to an occupied product line.
- It replaces the existing firm only if it is more productive.

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Distribution

- The distribution of product lines across x satisfies

$$g_x x f(x) = \delta F(x) + \int_{s \in (x - \lambda^i \bar{x}, x]} \xi(s) dF(s) + (1-p)(G(\infty) - G(x))F(x) - pG(x)$$

  where M is the number of the product lines.

- The distribution of expanding product lines is characterized by

$$G(x) = \int_{s \leq x} \zeta(s) dF(s) + \int_{s \leq x - \lambda^e \bar{x}} \chi dF(s).$$

- $\bar{x} := \int x dF(x) = \int_\Omega x_i di = 1.$

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Creative Destruction

- The creative destruction rate is then

$$\tau(x) = (1-p)\left(\chi\left(\int_{s>x-\lambda^e\bar{x}} dF(s)\right) + \int_{s>x} \zeta(s)dF(s)\right).$$

- The probability of being matched to a vacant line, p, is characterized by

$$\delta = Mp\int \zeta(s)dF(s) + \chi p.$$

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Free Entry and Labor Market Clearing

- The free entry condition is given by

$$wc_{\chi}\left(\chi\right)=\chi\left(\int\left(p+\left(1-p\right)F(x+\lambda^{e}\bar{x})\right)v(x+\lambda^{e}\bar{x})dF\left(x\right)\right)$$

  where $c_{\chi}\left(\chi\right)/\chi$ is increasing in χ.

- The labor market clearing condition is expressed as

$$wL=\frac{\sigma-1}{\sigma}+w\int_{0}^{1}c_{\xi}(\xi_{jt})dj+w\int_{0}^{1}c_{\zeta}(\zeta_{jt})dj+wc_{\chi}\left(\chi\right)$$

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Representative Household

- Suppose all the workers pool their income together through a perfect consumption insurance.
- The representative household maximizes the following lifetime utility.

$$\max_{C_t, L_t} \int_0^\infty e^{-\rho t} \left(\log(C_t) - \frac{\phi L_t^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}} \right) dt$$

subject to

$$C_t + \dot{b}_t = W_t(1-\tau_L)L_t + \int \pi_{jt} dj + r_t b_t + \tau_L W_t \tilde{L}_t$$

- On the BGP, $C_t = Y_t$ grows at the common rate g_Y, $w_t := W_t/Y_t = w$ is constant, and the first order condition becomes

$$r_t = r = \rho + g_Y$$
$$\phi \left(L_t\right)^{\frac{1}{\eta}} = \frac{W_t(1-\tau_L)}{C_t} = w(1-\tau_L)$$

- Zero net supply of real bonds, $b_t = 0$, $\forall t$.

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Aggregate Productivity Growth

- The growth rate on the BGP can decomposed into

$$
\begin{aligned}
g_x \bar{x} = & \underbrace{\int \left[\int_{s \in (x-\lambda^i \bar{x}, x]} M \xi(s) dF(s) \right] dx}_{\text{vertical innovation}} \\
& + p \underbrace{\int \left[\int_{s>x} M \zeta(s) dF(s) \right] dx - p \bar{\zeta} \bar{x}}_{\text{horizontal innovation (1)}} \\
& + p \underbrace{\int \left[\chi - \chi \int_{s \leq x - \lambda^e \bar{x}} dF(s) \right] dx - p \chi \bar{x}}_{\text{entrant innovation (1)}} \\
& + (1-p) \underbrace{\int \left(\int_{s>x} M \zeta(s) dF(s) \right) F(x) dx}_{\text{horizontal innovation (2)}} \\
& + (1-p) \underbrace{\int \left(\chi \int_{s > x - \lambda^e \bar{x}} dF(s) \right) F(x) dx}_{\text{entrant innovation (2)}}
\end{aligned}
$$

where $\bar{\zeta} := \int \zeta(s) dF(s)$ is the average horizontal innovation rate.

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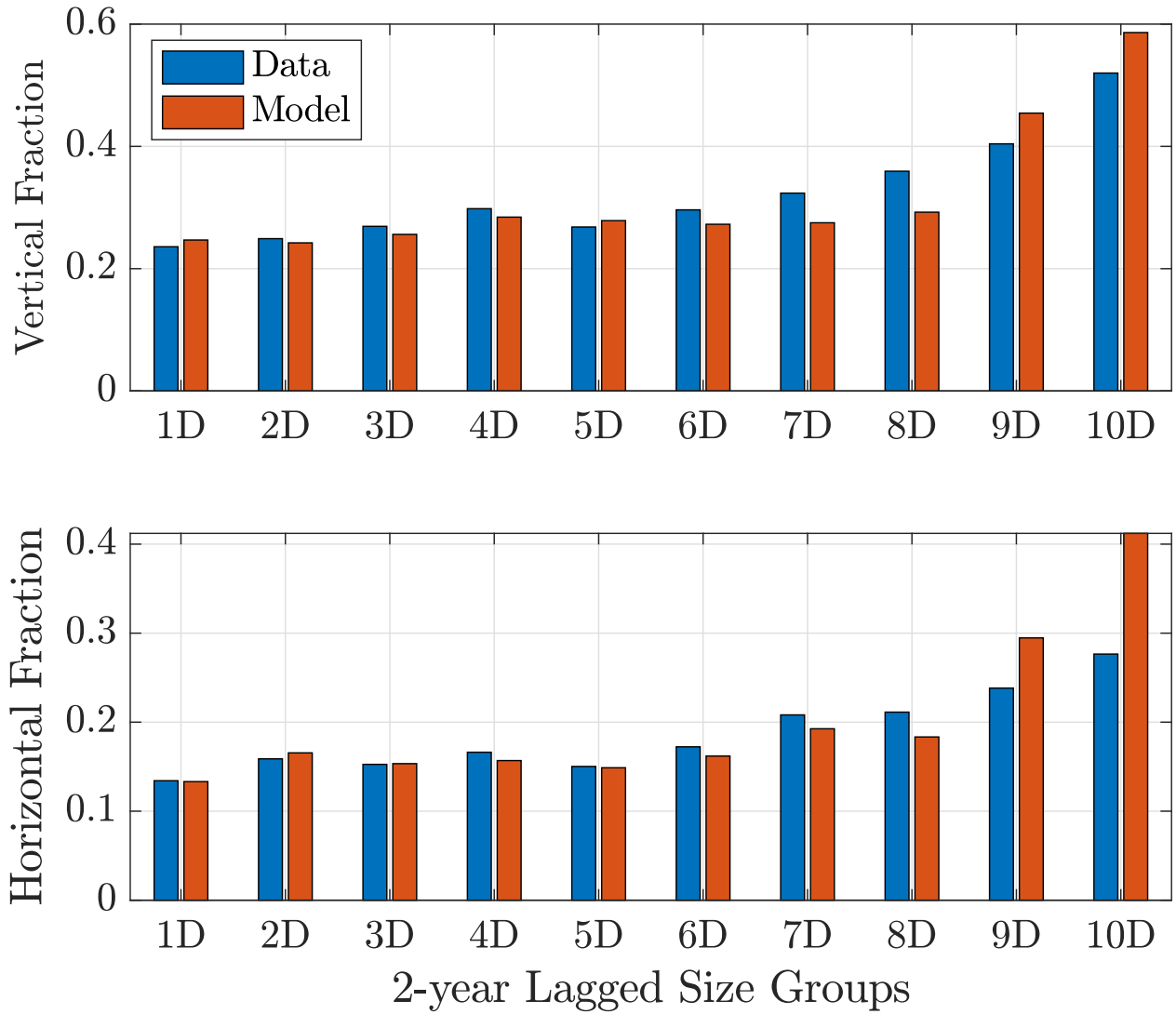
Model Fit for Untargeted Moments

- Model fit is overall good except on the largest establishments in 10D.



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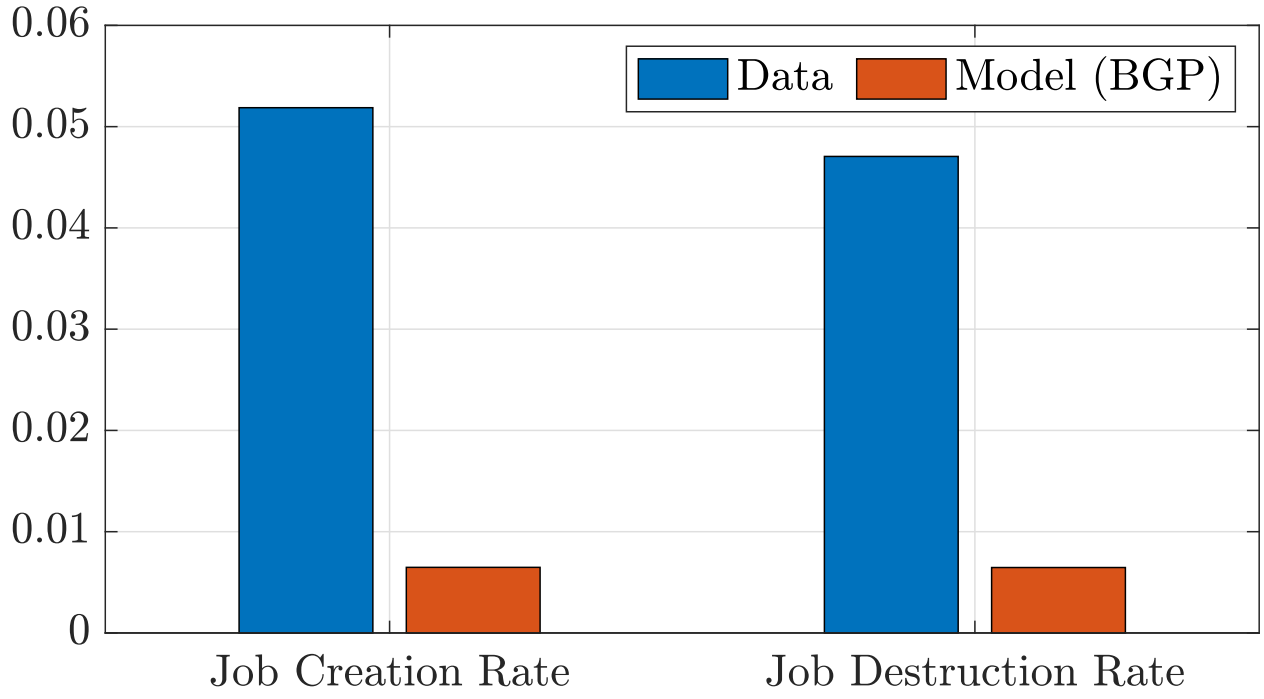
Model Fit for Untargeted Moments

- Model account for 12-15% of job turnover rates in the steady state.



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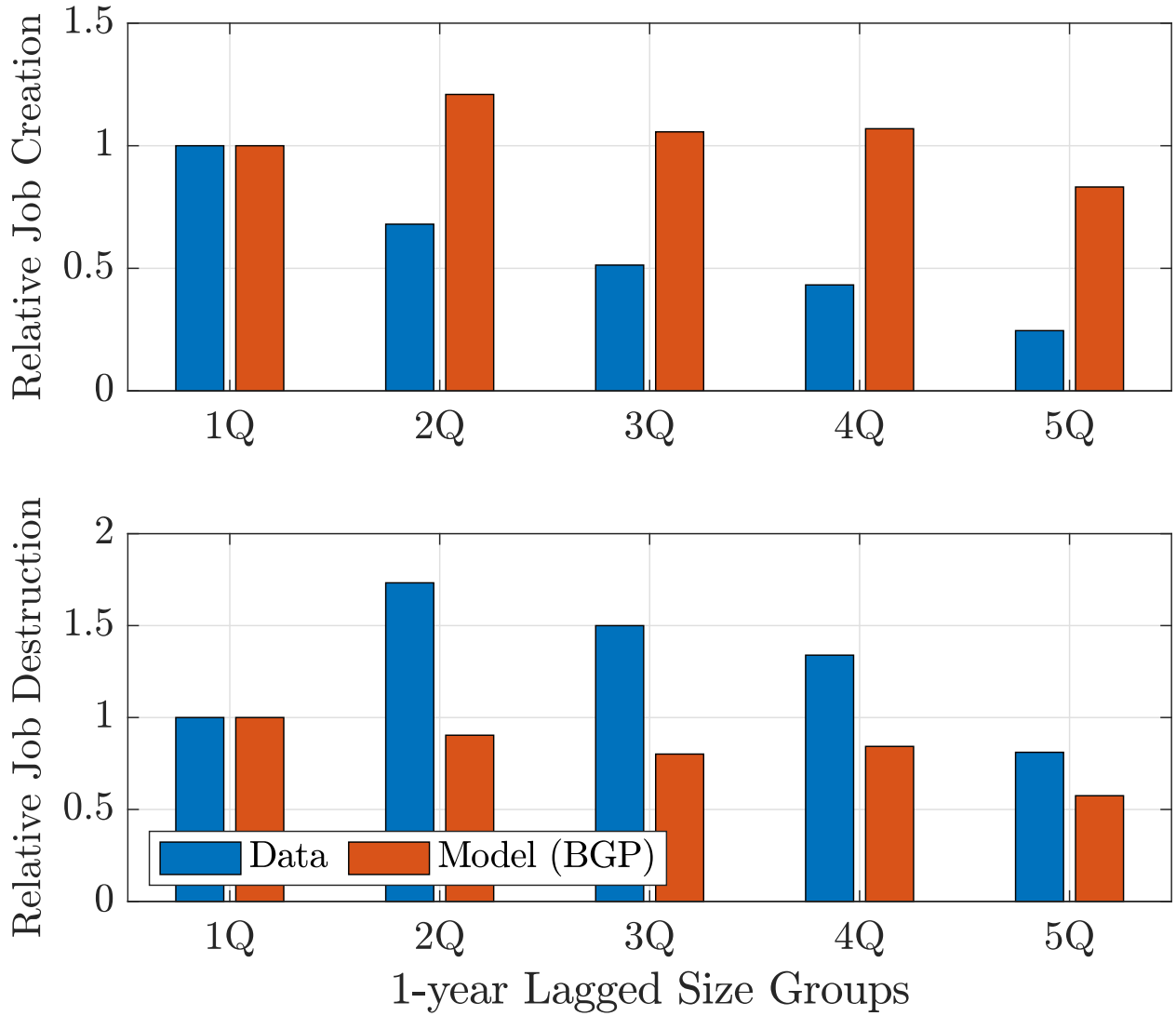
Model Fit for Untargeted Moments

- Model replicates turnover rates decreasing in size, but with a lower degree for job creation rates.



Alternative Elasticity Values

	Baseline	$\eta = 0.3$	$\eta = 4$	$\epsilon_\chi = 0$	$\epsilon_\chi = 1$
Change in Growth (ppt)	0.07	0.07	0.07	0.07	0.13
Change in Wage	-0.098	-0.096	-0.097	-0.098	-0.091
Change in R&D Share (ppt)	-1.82	-1.80	-1.81	0.34	-2.02
Change in Job Reallocation (ppt)	-0.00	-0.00	-0.00	-0.01	0.05
Change in Vertical Innovation (ppt)	0.82	0.81	0.82	0.82	0.80
Change in Horizontal Innovation (ppt)	0.01	0.01	0.01	0.01	0.01
%Change in Job Creation at $t = 6$	345	339	342	342	320
%Change in Job Destruction at $t = 6$	-29.3	-29.3	-29.3	-29.4	-27.8
%Change in Job Creation at $t = 36$	1.3	1.3	1.3	1.0	3.6
%Change in Job Destruction at $t = 36$	-2.4	-2.2	-2.4	-2.7	1.0
%Change in Job Creation at $t = 120$	1.3	1.3	1.3	1.0	3.6
%Change in Job Destruction at $t = 120$	-0.6	-0.5	-0.6	-0.9	2.8
CEV (%)	5.88	6.03	5.74	6.50	5.93
Initial Output Change (%)	0.97	0.97	0.99	1.05	1.16
Vertical Innovation (%)	0.83	0.82	0.82	0.83	0.85
Horizontal Innovation (%)	0.05	0.05	0.05	0.03	0.18
Entrant Innovation (%)	0.10	0.10	0.10	0.05	0.49
Labor Supply (%)	-3.26	-3.01	-3.35	-2.59	-3.40

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R&D Tax Incentive: Aggregate Moments

- 4.41% of subsidy rate starting at $t = 0$

Moment	Baseline	Vertical Subsidy	Horizontal Subsidy	Entrant Subsidy	All Subsidy
Output Growth Rate	1.30	1.33	1.31	1.30	1.33
Wage	1.000	1.001	1.001	1.005	1.007
R&D Labor Share	27.4	27.6	27.6	27.2	27.6
Labor Reallocation	1.73	1.74	1.74	1.73	1.75
Vertical Inovation	16.9	17.3	16.9	16.8	17.3
Horizontal Innovation	0.53	0.53	0.54	0.53	0.54
Job Creation from Vertical Innovation	26.2	26.6	26.2	26.1	26.6
Job Creation from Horizontal Innovation	26.8	26.7	27.1	26.8	26.9
Job Creation from Entrant Innovation	46.9	46.7	46.7	47.1	46.6
Job Destruction from Creative Destruction	13.2	13.1	13.3	13.2	13.3
Job Destruction from Obsolescence	29.0	29.4	29.1	29.1	29.5
Job Destruction from Exogenous Exit	57.8	57.5	57.6	57.7	57.2
Growth from Vertical Innovation	90.8	91.0	90.6	90.7	90.7
Growth from Horizontal Innovation	2.8	2.7	2.9	2.8	2.9
Growth from Entrant Innovation	6.4	6.3	6.5	6.5	6.5

R&D Tax Incentive: Aggregate Moments

- 4.41% of subsidy rate starting at $t = 0$

Moment	Vertical Subsidy	Horizontal Subsidy	Entrant Subsidy	All Subsidy
Consumption Equivalent Variation	0.20	-0.02	-0.70	-0.57
Initial Output Change	-0.14	-0.06	-0.49	-0.70
Vertical Innovation	0.39	0.01	-0.04	0.36
Horizontal Innovation	0.00	0.02	0.00	-0.01
Entrant Innovation	0.00	0.03	0.01	-0.01
Labor Supply	-0.05	-0.02	-0.19	-0.26
Catch-up Point (years)	5.4	14.4	-	28.5

Economy without Vertical Innovation

- Calibrate the same model but without vertical innovation.
- Model fit worse for incumbent job creation rates and entrant shares.
- Horizontal innovation alone not strong enough to make establishment growth.

Moment	Data	Model	Target
Growth Rate (%)	1.3	1.3	-
Fraction of Vertical Innovation (%)	29.4	-	
Fracion of Horizontal Innovation (%)	17.3	17.2	c_ζ
Fraction of Vertical Innovation (Medium - Small, ppt)	3.6	-	-
Fraction of Horizontal Innovation (Medium - Small, ppt)	2.0	2.4	ϵ_ζ
Employment Growth (Vertical - Average, ppt)	1.2	-	-
Employment Growth (Horizontal - Average, ppt)	1.4	0.8	q^h
Employment Growth (No Innovation - Average, ppt)	-1.6	-0.4	σ
Employment Share of Establishment Age ≤ 1 (%)	1.1%	1.9%	λ^i
Establishment Share of Establishment Age ≤ 1 (%)	1.9%	2.1%	χ

Decomposition without Vertical Innovation

Moment	Baseline	No Vertical
Job Creation from Vertical Innovation	26.2	-
Job Creation from Horizontal Innov.	26.8	23.0
Job Creation from Entrant Innovation	47.0	77.0
Job Destruction from Creative Destruction	13.1	20.7
Job Destruction from Obsolescence	29.0	3.8
Job Destruction from Exogenous Exit	57.8	75.5
Growth from Vertical Innovation	90.8	-
Growth from Horizontal Innovation	2.8	16.7
Growth from Entrant Innovation	6.4	83.3

The Hartz Exercise without Vertical Innovation

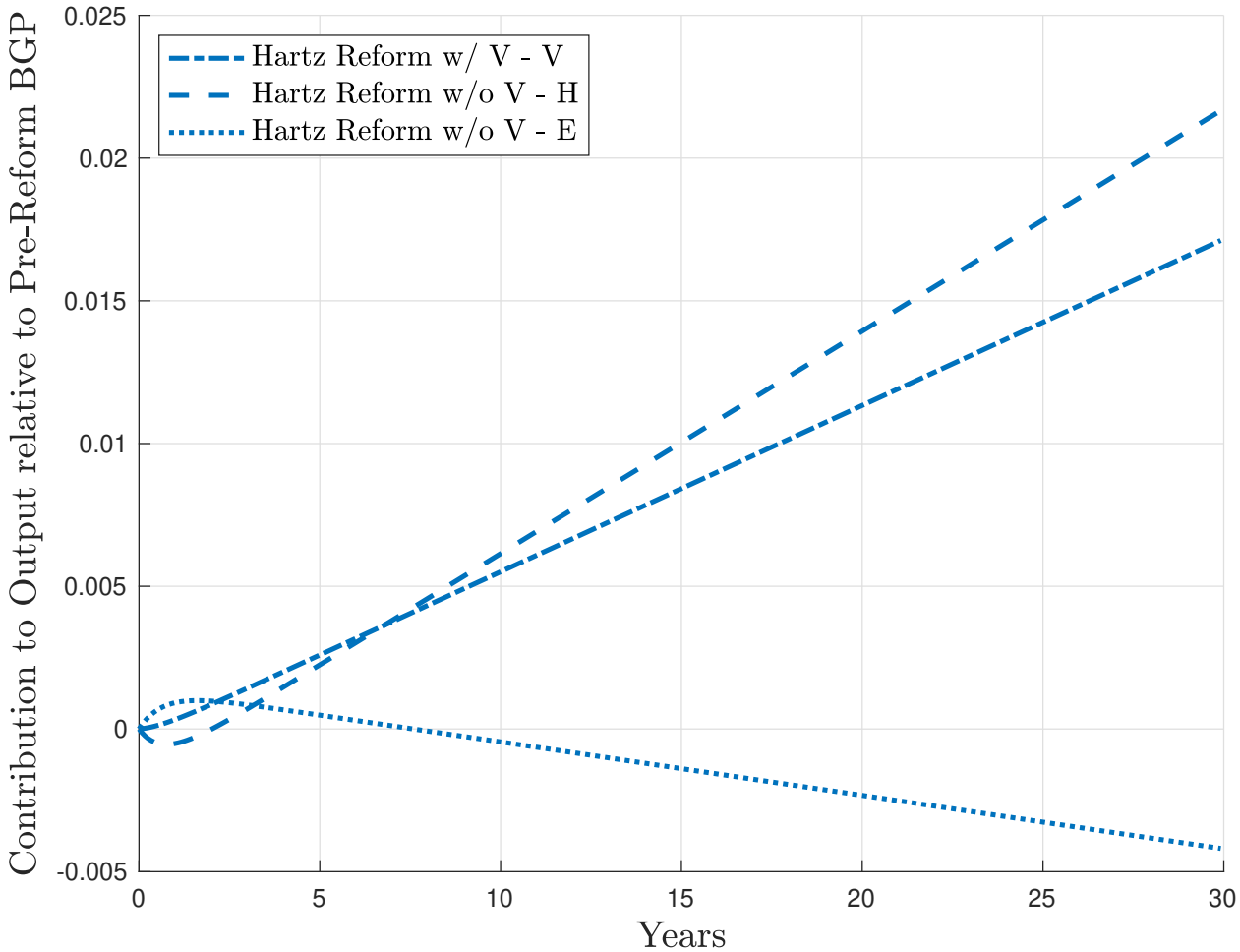
- Match the same S-S decrease in wage after the reform with and without vertical innovation.
  $\Rightarrow$ The same innovation cost reduction
- Without vertical innovation, the model predicts an increase in reallocation.

Moment	Baseline	No Vertical
Change in Output Growth Rate (ppt)	0.07	0.07
Change in Wage	-0.0981	-0.0982
Change in R&D Labor Share (ppt)	-1.8	-0.1
%Change in Avg. Job Reallocation Rate	-0.2	0.5
Change in Vertical Innovation (ppt)	0.8	-
Change in Horizontal Innovation (ppt)	0.01	0.01

The Hartz Exercise without Vertical Innovation

- Increase in productivity from horizontal innovation, but canceled out by the entrant innovation margin

$\Rightarrow$ Similar productivity growth over the transition path



The Hartz Exercise without Vertical Innovation

- Without vertical innovation, a much smaller decrease in job destruction in the SR, an increase in job destruction in the MR.

	Baseline	No Vertical
%Change in Job Creation at $t = 6$	345	595
%Change in Job Destruction at $t = 6$	-29.3	-3.7
%Change in Job Creation at $t = 36$	1.4	15.9
%Change in Job Destruction at $t = 36$	-8.6	-3.7
%Change in Job Creation at $t = 120$	1.3	4.2
%Change in Job Destruction at $t = 120$	-0.6	2.1

The Hartz Exercise without Vertical Innovation

- Smaller welfare gains from productivity growth.

	Baseline	No Vertical
Consumption Equivalent Variation	5.87	7.44
Initial Output Change	0.97	-2.41
Vertical Innovation	0.83	-
Horizontal Innovation	0.05	1.00
Entrant Innovation	0.10	-0.14
Labor Supply	-3.27	-1.32

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