Gig Workers and Performance Pay

A Dynamic Equilibrium Analysis of an On Demand Industry

Cedefop, Eurofound and IZA Conference

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From Mass Production to Mass Customization

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Consumers Want More Product Customization, But Manufacturers May Not Be Able To Deliver

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From start-ups to big brands, businesses are offering personalized product options to extend their product lines and increase sales.

Challenging Transformation

Q: How?

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Q: How?

A: Flexible and responsive production chain

In This Paper: **Labor Input Instruments**

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1. Adjustable labor force size

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2. Responsive production rates

Gig Workers

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Pay for Performance

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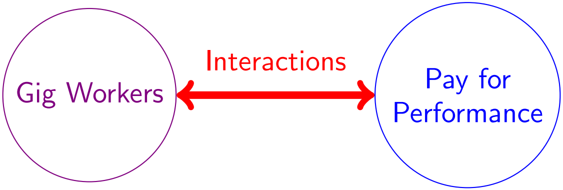

Fixing Terminology

Worker's Type: *Gig Worker* and *Permanent Worker*

Gig Worker

Gig worker is a worker under contingent or alternative employment arrangements, with no implicit or explicit contract for long-term employment[1]

[1] U.S. Department of Labor, Bureau of Labor Statistics

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Performance Pay: Bonus incentive pay

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Mass Customization

The mass production of individually customized good

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Research Questions

Goal

What is the optimal labor management of a firm that operates an on-demand customized production process?

> ⇒ What are the optimal combinations of pay scheme and workforce composition for a firm to optimally operate a customized manufacturing process?

1. **Labor Supply: Workers' Effort**
   What is the effect of bonus pay incentives on production and output quality?
   Does production response vary by worker's type?
2. **Labor Demand: Fundamentals of the Firm's Behavior**
   What is the underlying cost structure defining the firm's hiring schedule?

Solution Illustration Related Literature

Data: Global Mid-Size Manufacturer

Product: Customized fashion accessories

Strict Production Policy

- Up to 4 days of production within plants
- Minimum lead time

Sophisticated Digital Production System

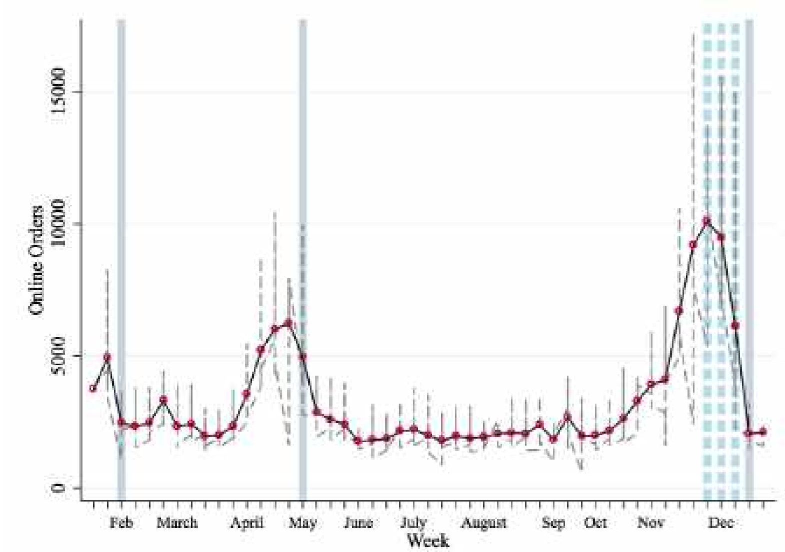
- Documents employees daily production of low- and high-quality items

Labor Management

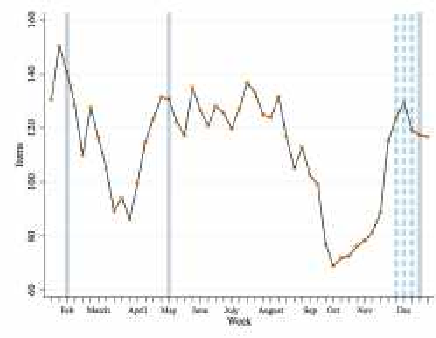
- Use on-demand workforce
- Switch between *flat wage* and *performance-based wage*

Product Demand

Average Daily Orders Over the Weeks of 2018



Production and Number of Workers



(a) Production per Worker

(b) Number of Workers by Type

Combined | Share of Gig by Month | On-The-Job Learning

Workers Data

	Worker Type		
	Permanent	*Gig*	*t*-Stat
Female	0.86	0.83	0.57
Age	32.27	24.27	4.85
Shift Length	7.22	8.00	-3.78
Experience $_{\text{Days}}$	328.68	23.35	14.67
Total Production $_{\text{Adj}}$	122.02	97.50	5.12
Low-Quality Production $_{\text{Adj}}$	2.45	3.41	-2.88
Production Score $_{\text{Adj}}$	155.41	138.67	1.65
N	44	216	

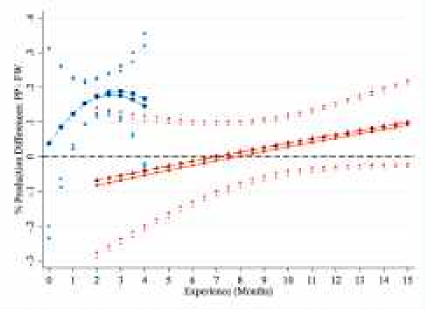
Notes: Production measures are adjusted to 8 hours of work.

Stylized Facts

$$\log(Y_{id}) = \gamma_0 + \beta_{\text{Gig}}\text{Gig}_i + \beta_{\text{PP}}\text{PP}_d + \beta_{\text{Exp.}}\text{Exp.}_{id} + \beta_{\text{Exp.}^2}\text{Exp.}^2_{id} + \beta_{\text{Exp.}\times\text{Gig}}(\text{Exp.}\times\text{Gig})_{id} + \beta_{\text{Exp.}^2\times\text{Gig}}\left(\text{Exp.}^2\times\text{Gig}\right)_{id}$$
$$+ \beta_{\text{Exp.}\times\text{PP}}(\text{Exp.}\times\text{PP})_{id} + \beta_{\text{Exp.}^2\times\text{PP}}\left(\text{Exp.}^2\times\text{PP}\right)_{id} + \beta_{\text{PP}\times\text{Gig}}(\text{PP}\times\text{Gig})_{id} + \delta_i + C_{id} + \varepsilon_{id}$$

Fact:

Gig and permanent workers hold different intrinsic motives and job perception



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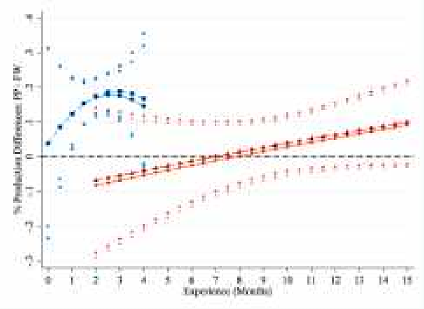

Sources of heterogeneity

- Effort cost
- Intrinsic motivation

$\}$ Explored in the model

Overview of Equilibrium Model

1. The Worker's Problem
   - Heterogeneous workers make daily effort choices
   - Take as given the pay scheme offered by the firm
   - Experience a daily productivity shock

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   - Makes weekly decisions regarding labor force composition and pay scheme offered
   - Subject to product demand shocks
   - Not imposing optimality of the wage structure

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3. Counterfactual Simulations:
   - Utilitarian approach
   - A central planer perspective

The Worker's Effort Decision

On each given day, d, a risk-neutral worker, i, wishes to maximize her utility

$$\max_{E_{i\nu d}\in(0,1]} W_{i\nu d}(E,X) - C_{i\nu d}(E,X)$$

s.t.

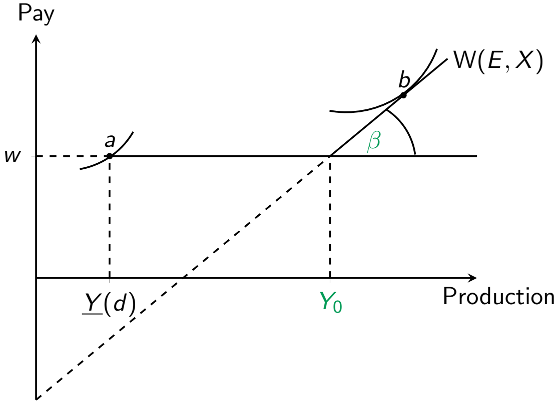
$$W_{i\nu d}(E,X) = \max\left\{w, w + \beta(Y^{\text{HQ}}_{i\nu d}(E,X) - Y_0)\right\}$$

$$\mathbb{E}\left[Y^{\text{HQ}}_{i\nu d}\right] \geq \underline{Y}(d)$$

Production Function | Effort Cost | Solution Method: Indirect Inference

Wage Structure

$$W = \begin{cases} w & \text{if Fixed wage} \\ \max\left[w, w + \beta(Y^{\text{HQ}}(E,X) - Y_0)\right] & \text{if Performance pay} \end{cases}$$



The Firm's Problem

Overview

- Objective: Minimize labor cost
- Time: weeks in a calendar year
- Observables:
  - Number of permanent and gig workers
  - Wages (flat rate and bonuses)
  - Bonus pay structure: (Y_0, β)
- Constraints:
  - Demand uncertainty: ζ_t
  - Workers incentive compatibility constraints: $Y_t(E_t^*)$
- Decision:

$$d_k = \left(\overbrace{z_t}^{\substack{\text{Pay Scheme} \\ \text{FW or PP}}}, \overbrace{P_t^N}^{\text{New Permanent}}, \overbrace{\boldsymbol{P_t^L}}^{\substack{\text{Laid Off} \\ \text{Permanent}}}, \overbrace{G_t^N}^{\text{New Gig Workers}} \right)$$

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The Firm's Problem
Details

- State Variables

  P_{t-1}: the number of permanent workers employed in week $t-1$

  TC_{t-1}: the tenure record of permanent workers P_{t-1}

- Labor Force Tenure Record

  - Permanent workers

$$\text{Tenure Category}_t = \begin{cases} C_1 & \text{if} \quad X_t \leq 3, \\ C_2 & \text{if} \quad 3 < X_t \leq 30, \\ C_3 & \text{if} \quad 30 < X_t \end{cases}$$

  - Gig workers tenure evolves weekly

Dynamic Stochastic Model of Labor Force Hiring and Compensation Scheme

$$V_t\left(P_{t-1}, TC_{t-1}\right) = \max_{k \in K(t)} \left[V^k\left(P_t, TC_t\right) \right],$$

$$V_t^k\left(P_{t-1}, TC_{t-1}\right) = \begin{cases} -\text{Cost}_t^k(P_{t-1}, TC_{t-1}) & \\ \qquad +\psi\,\mathbb{E}\left[V_{t+1}\left(P_t, TC_t\right) | d_k(t) = 1, P_{t-1}, TC_{t-1} \right] & \text{for } t < T, \\ -\text{Cost}_t^k(P_T, TC_T) & \text{for } t = T \end{cases}$$

such that,

$$P_t = (1-\mu)P_{t-1} - \boldsymbol{P_t^L} + P_t^N$$

$$P_t^L \leq (1-\mu)P_{t-1}$$

$$G_t = G_t^N$$

$$E_{it}^{*z} = \arg\max_E (U_{it} - C_{it}|z)$$

$$\sum_{i=1}^{P_t} \mathbb{E}\left[Y_{it}(E^*, z|TR_{it}) \right] + \sum_{i=1}^{G_t} \mathbb{E}\left[Y_{it}(E^*, z|X_{it}) \right] = D_t(\zeta_t)$$

$\zeta_t \sim \mathcal{N}(0, \sigma_D)$ serially independent

Labor Cost Function

$$\text{Cost}_t(P_t, TC_t) = \sum_{i=1}^{P_t} \mathbb{E}\left[W_{it}(E^*, z | TR_{it})\right] + \sum_{i=1}^{G_t} \mathbb{E}\left[W_{it}(E^*, z | X_{it})\right]$$
$$+ \Big(\underbrace{R^P}_{\substack{\text{Recruiting cost} \\ \text{permanent workers}}} \cdot P_t^N + \underbrace{L^P}_{\substack{\text{Lay off cost} \\ \text{permanent}}} \cdot \boldsymbol{P_t^L} \Big) + \Big(\underbrace{R^G}_{\substack{\text{Recruiting cost} \\ \text{gig workers}}} \cdot G_t^N \Big)$$

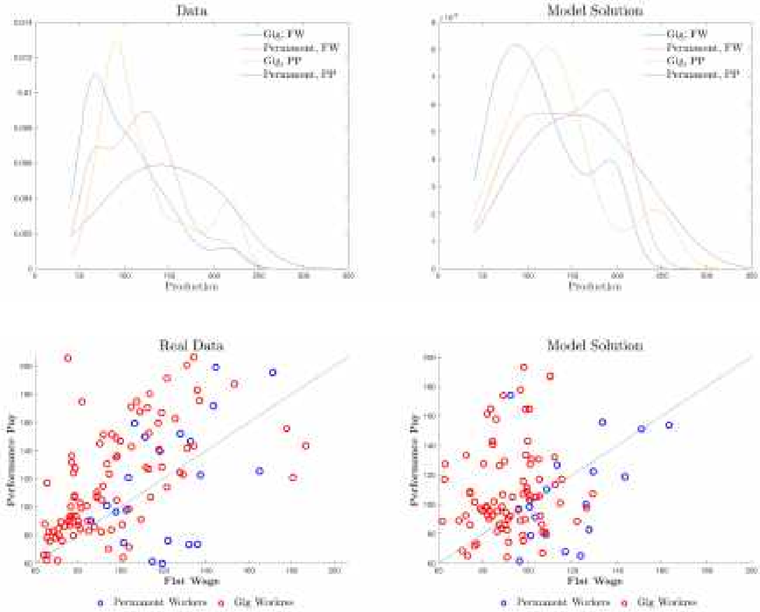
Solution Method: Simulated Maximum Likelihood

Labor Supply: Estimates of Structural Parameters

Parameters Description	Symbol	Estimate	SD
Total Factor Productivity			
Gig Worker	α_g	48.26	4.1
Permanent	α_p	40.63	5.18
Personal Motivation			
Gig Worker	η_g	300.023	7.5
Permanent Worker	η_p	194.91	5.7
Effort Cost Convexity			
Gig Worker	γ_g	2.40	0.26
Permanent Worker	γ_p	1.3	0.18
Experience Elasticity	δ	0.1494	0.003
Effort Effect on Low Quality Production	ϕ_E	10.69	1.95
Experience Effect on Low Quality Production	ϕ_X	-38.57	5.95

Auxiliary Model: Parameters Fit Model Fit

Model Fit



Data
Gig, FW
Permanent, FW
Gig, PP
Permanent, PP
Production
Model Solution
Gig, FW
Permanent, FW
Gig, PP
Permanent, PP
Production
Real Data
Performance Pay
Flat Wage
Permanent Workers
Gig Workers
Model Solution
Performance Pay
Flat Wage
Permanent Workers
Gig Workers

Labor Demand: Estimates of Structural Parameters

Parameters Description	Symbol	Estimate	SD
Separation rate	μ	0.07	0.001
Recruiting permanent worker	R^P	296.81	10.88
Laying off permanent worker	L^P	230.57	9.14
Recruiting gig worker	R^G	112.67	8.44

Back-of-the-envelope calculations

The firm could reduce the labor cost during peak seasons by 22% by integrating the hiring of gig workers and the implementation of bonus incentive pay.

Conclusions

Main Findings

1. Gig workers demonstrate a production response to incentives six times higher than that of permanent workers.
2. Gig workers are facing higher effort cost than permanent workers
3. Gig workers hold 50% higher personal motivation than permanent workers
4. Output quality significantly increases with worker's experience, and decreases with worker's effort
5. The firm could reduce the labor cost during peak seasons by 22% by integrating the hiring of gig workers and the implementation of bonus incentive pay.

Production and Number of Workers By Type

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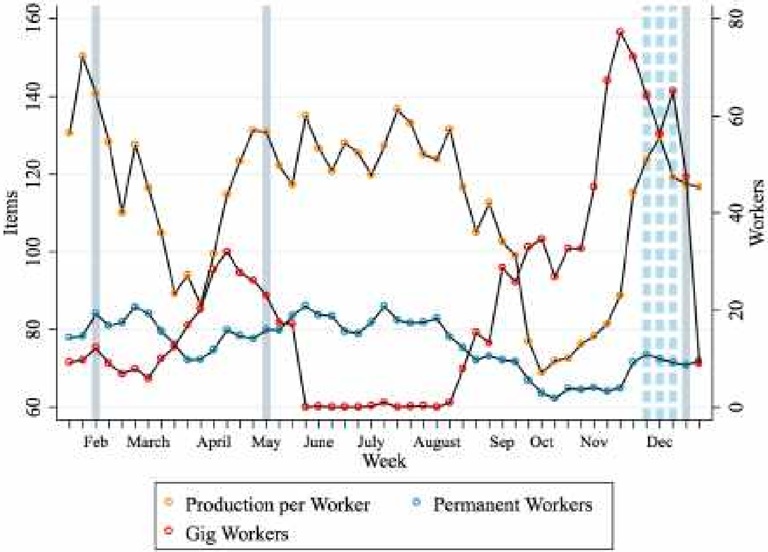

Share of Gig Workers by Month

Table: Share of Gig Workers

	Mean	SD	*N*
February	0.408	0.497	49
March	0.537	0.502	67
April	0.608	0.491	79
May	0.565	0.499	85
June	0.091	0.292	33
July	0.057	0.236	35
August	0.279	0.454	43
September	0.644	0.482	73
October	0.842	0.367	95
November	0.843	0.365	140
December	0.723	0.449	141
Total	0.614	0.487	840

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Defective Production and Gig Workers

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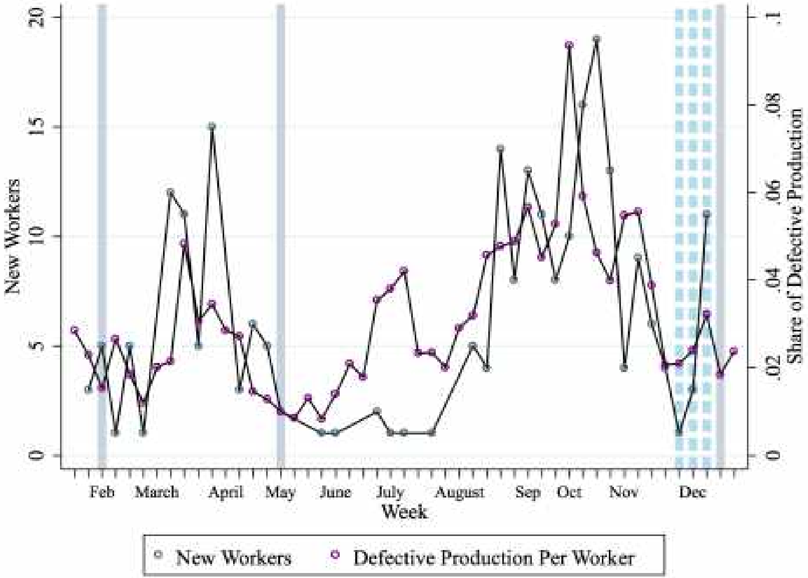

Empirical Evidence: Gig Workers and Production

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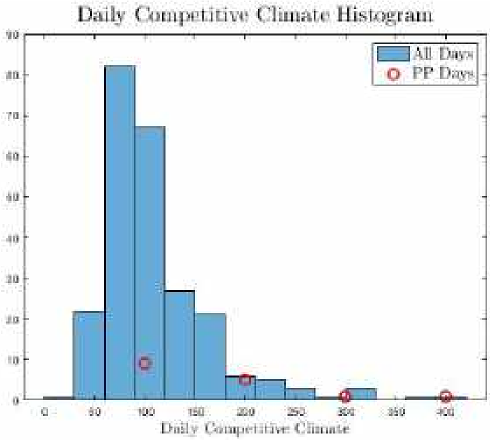
	Dependent Variable: Log of Worker's Daily High-Quality Production (Adj)			
	(1)	(2)	(3)	(4)
Performance Pay	0.101**	-0.0211	0.101**	-0.0159
	(0.0147)	(0.116)	(0.0149)	(0.0617)
Daily Demand	0.0396**	0.0382**	0.0320**	0.0323**
	(0.00210)	(0.00211)	(0.00192)	(0.00192)
Daily Number of Workers	-0.00468**	-0.00469**	-0.00197**	-0.00193**
	(0.000315)	(0.000318)	(0.000318)	(0.000324)
Gig Worker	-0.244**	-0.199**		
	(0.0744)	(0.0837)		
Experience	0.0167	0.0214	-0.0373	-0.0322
	(0.0187)	(0.019)	(0.0339)	(0.0340)
Gig Worker × Experience	0.0238	0.0860	0.432**	0.422**
	(0.0508)	(0.0544)	(0.0254)	(0.0282)
Experience^2	-0.00176**	-0.00161*	0.00183	0.00194
	(0.000849)	(0.000860)	(0.00355)	(0.00355)
Gig Worker × Experience^2	0.0215*	0.00954	-0.0937**	-0.0970**
	(0.0124)	(0.0129)	(0.00718)	(0.00827)
Performance Pay× Gig Worker		0.394**		
		(0.122)		
Performance Pay× Gig Worker × Experience		-0.273**		0.108*
		(0.0597)		(0.0643)
Performance Pay × Gig Worker × Experience ^{2}		0.0512**		-0.0152
		(0.0147)		(0.0153)
Constant	4.943**	4.860**	4.782**	4.776**
	(0.0741)	(0.0824)	(0.0549)	(0.0551)
Gender Interactions	No	Yes	No	Yes
Team FE	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
N	8179	8179	8179	8179
R^2	0.242	0.247	0.433	0.434

Standard errors are in parentheses.
Controls: Day of the week indicator, holiday dummy, repeated employment, and employment in more than one department.
Demand is measured in thousands of units, and experience is measured in groups of 30 days.
* $p < 0.10$, ** $p < 0.05$

Competitive Climate

$$\kappa_d := \left(\frac{\text{Daily Demand}}{\text{Daily \# of Workers}} \right)$$



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Weight Matrix Estimation

Estimation is done in two steps.

1. At the first step it is set to be equal to the inverse of a diagonal matrix with the standard errors of the parameters of the auxiliary model on the main diagonal.
2. The second step calculates the variance-covariance matrix of the simulated auxiliary parameters, ψ_{sim},

$$\hat{W} = \frac{1}{L}\sum_{l}^{L}\left(\psi_{\text{sim}}^{l}(\sigma_{\varepsilon}^{1}) - \frac{1}{L}\sum_{l}^{L}\psi_{\text{sim}}^{l}(\sigma_{\varepsilon}^{2})\right)\cdot\left(\psi_{\text{sim}}^{l}(\sigma_{\varepsilon}^{1}) - \frac{1}{L}\sum_{l}^{L}\psi_{\text{sim}}^{l}(\sigma_{\varepsilon}^{2})\right)'$$

where σ_{ε}^{j}, $j = 1, 2$ are different sets of L realizations of the idiosyncratic production shock, and L is equal to 1000.

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Solution Process Details

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1. Solve for workers' daily effort decision for a vector of possible values of structural parameters, based on the FOC of the problem
   - Flat Wage: $\beta = 0$

$$\frac{\kappa_d}{X_{id}}\gamma\left(E_{id}^{*\mathrm{FW}}\right)^{(\gamma-1)} = \eta_{id}$$

   - Performance Pay: $\beta > 0$

$$\beta\left[1-\rho_{id}\right]\alpha X_{id}^{\delta}\mathrm{e}^{\varepsilon_{id}}\mathbb{I}_{\mathrm{PP}} + \eta_i = \frac{\kappa_d}{X_{id}}\gamma\left(E_{id}^{*\mathrm{PP}}\right)^{(\gamma-1)} + \beta\left[\rho_{id,E}\right]\alpha\left(E_{id}^{*\mathrm{PP}}\right)X_{id}^{\delta}\mathrm{e}^{\varepsilon_{id}}\mathbb{I}_{\mathrm{PP}}$$

2. Calculate the optimal production based on the solution and the set of chosen parameters
3. Estimate the auxiliary model coefficients $\psi_{\text{sim}}(\Theta)$
4. Search for $\hat{\Theta}_{\omega}$ that minimize the distance between the auxiliary parameters estimated on the actual data and the auxiliary parameters estimated from the simulated data

Identification of Structural Parameters

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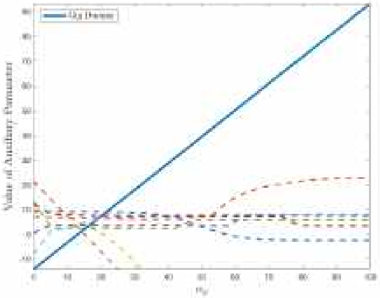
1. Exogenous variation in observable variables and the first order conditions solution
   Experience, pay scheme, number of workers, demand
2. Monte Carlo Simulations
   Start with known parameters and recover the value of the parameters precisely using the estimation procedure
3. Perturbation
   Examine the relationship between the parameter of the structural model and parameters of the auxiliary model obtained by simulations



Model Fit of Auxiliary Parameters

Auxiliary Parameters	Simulated	Target
β_0	85.71	85.88
β_{PP}	-3.07	-4.33
β_{Gig}	-13.21	-13.76
$\beta_{\text{Exp.}}$	2.74	2.12
$\beta_{\text{Exp.}^2}$	-0.047	-0.023
β_{Female}	11.45	12.69
$\beta_{\text{Daily Demand}}$	1.97	2.74
$\beta_{\text{PP}\times\text{Gig}}$	22.97	23.25

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Production Averages by Pay Scheme and Worker's Type

Parameters Description	Data	Model Solution
Gig worker under Flat Wage		
0-20	88.086	80.132
20-40	105.99	105.27
40-60	123.19	118.84
Gig worker under Performance Pay		
0-20	137.52	130.94
20-40	118.89	115.12
40-60	121.99	120.15
Permanent worker under Flat Wage		
0-30	122.90	110.82
30-90	119.79	114.17
90-120	115.28	114.96
120-210	110.75	117.75
$>$210	133.6	128.48
Permanent Worker Under Performance Pay		
0-270	108.78	110.39
270-360	120.06	121.50
$>$360	154.85	150.99

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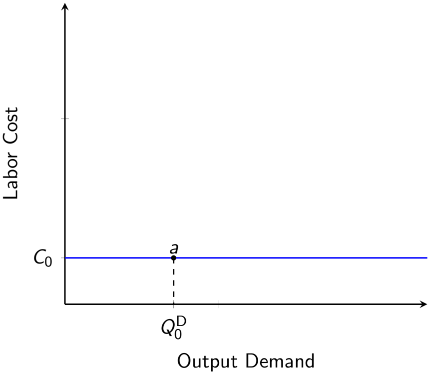
Alternative Solutions



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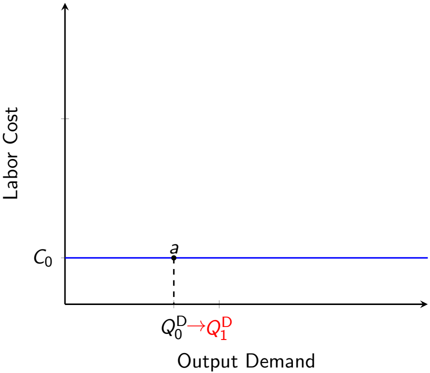

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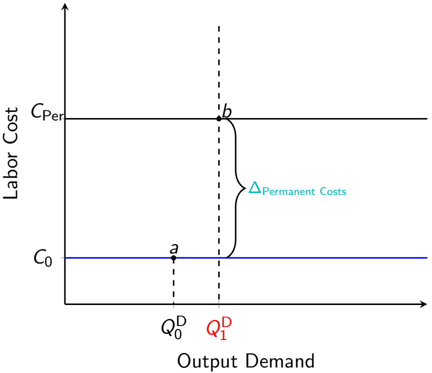

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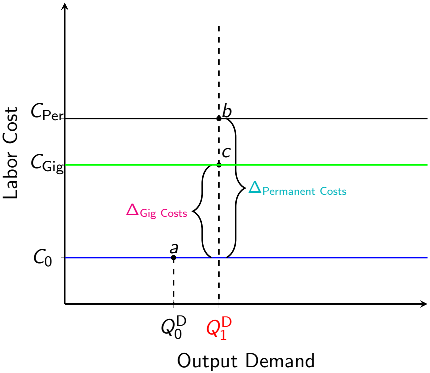

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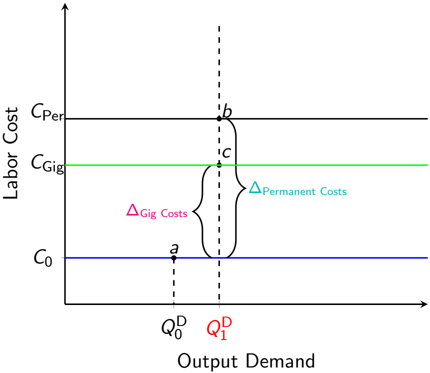
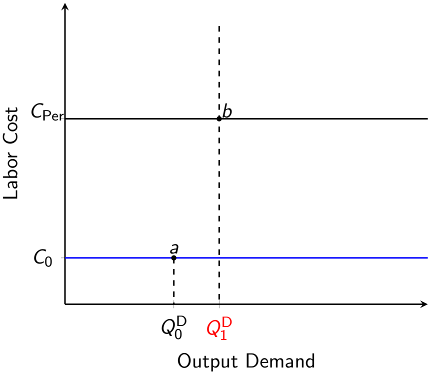


1. **If** ΔGig Costs $<$ ΔPermanent Costs

$\Rightarrow$ Hire gig workers before anticipated demand peaks

- On-the-job learning
- Recruiting costs

Alternative Solutions



1. **If** ΔGig Costs $<$ ΔPermanent Costs

$\Rightarrow$ Hire gig workers before anticipated demand peaks

- On-the-job learning
- Recruiting costs

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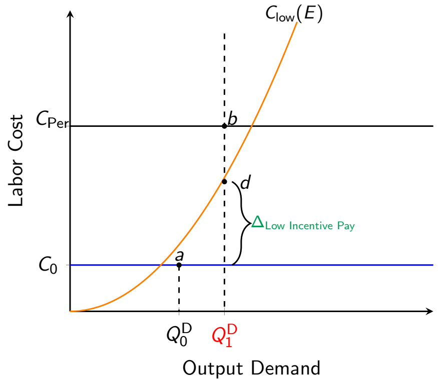

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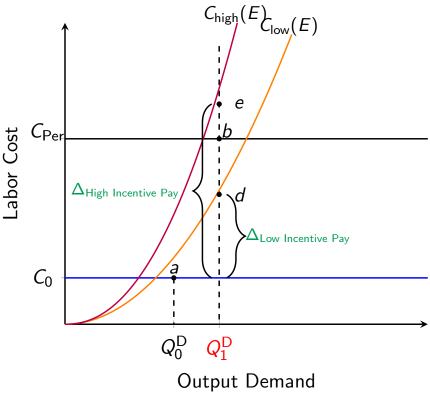

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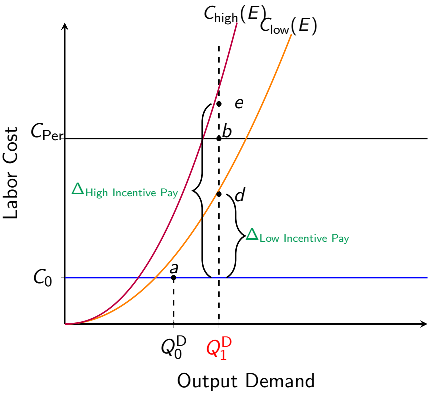

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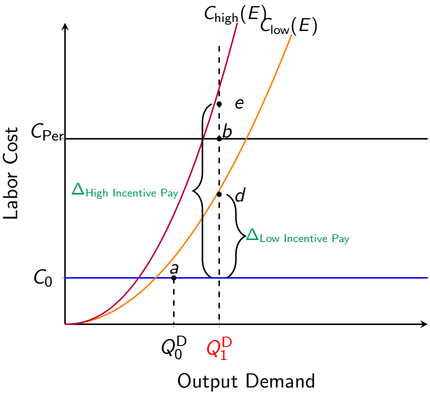

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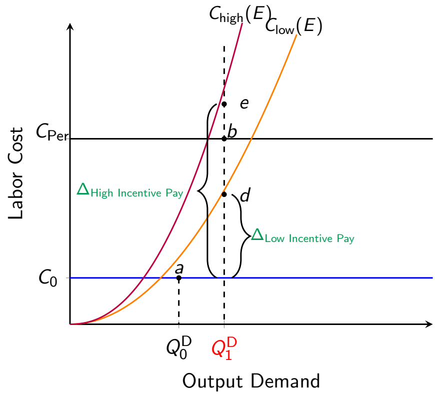
Alternative Solutions



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Findings Preview Back

Related Literature

Payment Scheme

- **Labor & Personnel Economics**
  Shearer (2004); Bellemare & Shearer (2011); Freeman & Kleiner (2005)
- **Operational Decisions in the Gig-Economy**
  Chen & Sheldon (2016); Hall et al. (2018); Allon et al. (2018)
- **Efficiency Wages**
- **Tournament Theory**

Workforce Composition

- **Personnel Scheduling**
  Pinker & Larson (2003); Bard (2004b); Stratman et al. (2004); Dong & Ibrahim (2017)

This Paper

- Structural estimation of an equilibrium framework with decisions related to the payment scheme (contract design) and the workforce composition

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Production Function

- Total Production

$$Y_{i\nu d}^{\text{Total}} = \alpha_\nu E_{i\nu d} X_{i\nu d}^{\delta} e^{\varepsilon_{id}}$$

$$\alpha_\nu = \alpha_p \mathcal{I}\{Permanent_i = 1\} + \alpha_g \mathcal{I}\{Gig_i = 1\}$$

$$\varepsilon_{i\nu d} \sim N(0, \sigma_\varepsilon)$$

- High Quality Production

$$Y_{i\nu d}^{\text{HQ}} = \left[1 - \bar{\rho}_{i\nu d}(E, X)\right] Y_{i\nu d}^{\text{Total}}$$

- Defective Production Probability

$$\bar{\rho}_{i\nu d}(E, X) = \frac{\exp\left(\phi_E E_{i\nu d} + \phi_X X_{i\nu d}\right)}{1 + \exp\left(\phi_E E_{i\nu d} + \phi_X X_{i\nu d}\right)}$$

Back

Effort Cost Function

κ_d

$$C_{i\nu d}(E,X) = \frac{\kappa_d}{X_{i\nu d}} E_{i\nu d}^{\gamma_\nu} - \eta_\nu E_{i\nu d}$$

$$\text{Such that: } \gamma_\nu = \gamma_p \mathcal{I}\{Permanent_i = 1\} + \gamma_g \mathcal{I}\{Gig_i = 1\}$$
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Assumptions

A1 $\eta_\nu > 0 \Rightarrow$ Employees supply positive effort under a flat wage.

A2 $\gamma > 1 \Rightarrow$ Convex in effort, $C_{EE} > 0$.

A3 More experienced workers face a lower marginal effort-cost (other things equal): $C_{EX} < 0$

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Solution Method: Indirect Inference

Parameters

$$\Theta_\omega = (\alpha_g, \alpha_p, \delta, \eta_g, \eta_p, \gamma_g, \gamma_p, \phi_E, \phi_X, \sigma_\varepsilon)$$

Auxiliary Parameters

Let $\psi(\Theta_\omega)$ be the vector auxiliary parameters

General Idea

Repeat simulations to find the data-generating parameters, $\hat{\Theta}_\omega$, that minimizes the distance between the auxiliary parameters and the parameters estimated from the actual data,

$$\hat{\Theta}_\omega = \arg\min_{\Theta_\omega} \Big(\hat{\psi}_{\text{data}} - \psi_{\text{sim}}(\Theta_\omega)\Big) \mathrm{W} \Big(\hat{\psi}_{\text{data}} - \psi_{\text{sim}}(\Theta_\omega)\Big)'$$

where W is a symmetric and positive semi-definite weighting matrix.

Weight Matrix Details | Identification | Solution Process Details | Back

Solution Method: Simulated Maximum Likelihood

Parameters

$$\Theta_F = (\mu, R^P, L^P, R^G)$$

Likelihood

The probability that the firm is observed to choose alternative k_t at week t is defined by

$$\mathcal{P}\left(k_t|\Omega_t^d\right) = \mathcal{P}\left(\max_j\left[V_{jt}(\Omega_t)\right]\right)$$

Define the likelihood function as follows

$$\mathcal{P}\left(k_1, ..., k_T|\Omega_1^d\right) = \prod_{t=1}^{T} \mathcal{P}\left(k_t|\Omega_t^d\right)$$

- The probabilities are calculated using the Kernel Smoothed Frequency Simulator proposed by McFadden (1989)
- Use Keane and Wolpin (1994) Simulation Interpolation Method to deal with a state space that exponentially increases with the number of permanent workers

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