A. COSTINOT (MIT) AND I. WERNING (MIT)

ROBOTS, TRADE, & LUDDISM

MOTIVATION

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- **Technological Progress:** Efficiency (+) vs. Inequality (-)

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  1. When is technological progress welcomed?

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- **Questions**
  1. When is technological progress welcomed?
  2. How should government policy respond?

BACKGROUND

- **First Best:** Second Welfare Theorem
  - Lump-sum transfers ⇒ Redistribution without distortions
- **Second Best:** Diamond and Mirrlees (1971)
  - Unconstrained linear taxation ⇒ Production efficiency
  - No trade taxes; no taxes on robots

THIS PAPER

- **More realistic, restricted set of tax instruments**
  - After tax wages not fully controlled
  - before tax wages affected by policy (Naito 1999)
- **General framework**
  - Common principles: robots & trade
  - Theory delivers relevant sufficient statistics

RESULTS

1. When is technological change welcomed?

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    - Like in a first best world (despite not being first best)
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    - More robots/more trade may lower optimal taxes
    - No rationale for taxing/subsidizing innovation

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   - Like in a first best world (despite not being first best)
2. How should government policy respond?
   - Formulas/bounds, sufficient statistics...

     t = function of observable elasticities and shares*

     Key sufficient statistic: elasticity effect on wages

   - More robots/more trade may lower optimal taxes
   - No rationale for taxing/subsidizing innovation

RELATED LITERATURE

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- **Optimal Taxation**
  - Diamond and Mirrlees (1971a, b), Dixit and Norman (1986)
  - Naito (1999, 2006), Guesnerie (1998), Spector (2001), Jacobs (2015)
  - Mayer and Riezman (1987), Rodrik (1995), Grossman and Helpman (1994)

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- **Welfare impact of technological progress or openness:**
  - Efficiency: Solow (1957), Hulten (1978) Bhagwati (1971), Baeqee and Farhi (2017)
  - Distribution: Antras, de Gortari, and Itskhoki (2017), Galle, Rodriguez-Clare and Yi (2017)

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- **Optimal tax on robots:** Guerreiro, Rebelo, Teles (2017)

ROADMAP

- General Framework
- Valuation of New Technologies
- Optimal Taxation
- Application

GENERAL FRAMEWORK

HOUSEHOLDS

- Household skills $\theta \sim F(\theta)$
- Goods $i = 1, ..., N$
- Preferences

$$U = u(C, n)$$
$$C = v(\{c_i\})$$

TECHNOLOGY

- Old Technology

$$G(\{y_i\}, \{n(\theta)\}) \leq 0$$

- New Technology

$$G^*(\{y_i^*\}; \phi) \leq 0$$

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$$G^*(\{y_i^*\}; \phi) \leq 0$$

- Example I: Trade (small economy)

$$G^*(\{y_i^*\}; \phi) = \sum \bar{p}_i(\phi) y_i^*$$

- Example II: Trade (large economy)

$$G^*(\{y_i^*\}; \phi) = \sum \bar{p}_i(\{y_l^*\}, \phi) y_i^*$$

TECHNOLOGY

- Old Technology

$$G(\{y_i\}, \{n(\theta)\}) \leq 0$$

- New Technology

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- Example III: Robots (skilled-unskilled)

$$y = H(n_L, n_H, r)$$

- Example IV: Robots (task-based)

$$y = (\int y_i^{\frac{\epsilon-1}{\epsilon}} di)^{\frac{\epsilon}{\epsilon-1}}$$

$$y_i = \int a_i(\theta)n(\theta)d\theta + a_i(r)r_i$$

$$r^* = \phi y^*$$

EQUILIBRIUM (I): DEMAND

- Household solves

$$\max_{C,n} u(C,n)$$

$$e(\{q_i\},C) \leq R(w(\theta)n;\theta)$$

with

$$e(\{q_i\},C) \equiv \min_{\{c_i\}}\{\sum q_i c_i | v(c) \geq C\}$$

$$R(w(\theta)n;\theta) \equiv w(\theta)n - T(w(\theta)n;\theta)$$

EQUILIBRIUM (II): SUPPLY

- Old Technology firms

$$\max_{\{y_i\},\{n(\theta)\}} \sum p_i y_i - \int w(\theta) n(\theta) dF(\theta)$$

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$$\max_{\{y_i^*\}} \sum p_i^* y_i^*$$

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- Non-arbitrage

$$p_i = q_i/(1+t_i)$$

$$p_i^* = q_i/(1+t_i^*)$$

MARKET CLEARING

- Supply equals Demand for goods…

$$y_i + y_i^* = \int c_i(\theta) dF(\theta)$$

- Government budget constraint
  - net revenue from nonlinear taxes and linear taxes is zero
  - can be omitted by Walras' Law

$$\max_{C,n} u(C,n)$$

$$e(\{q_i\},C) \leq R(w(\theta)n;\theta)$$

$$\max_{\{y_i\},\{n(\theta)\}} \sum p_i y_i - \int w(\theta)n(\theta)dF(\theta)$$

$$G(\{y_i\},\{n(\theta)\}) \leq 0$$

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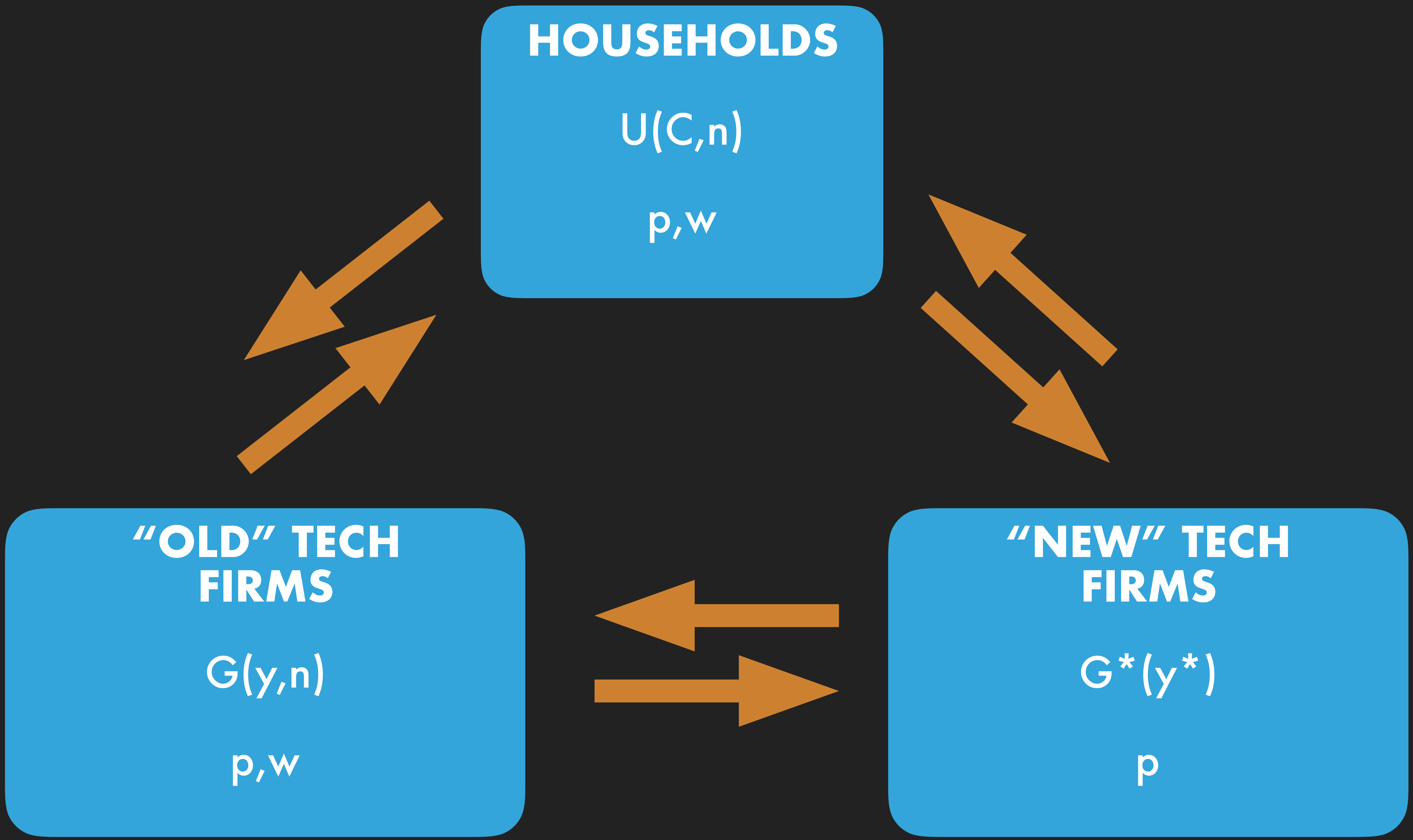
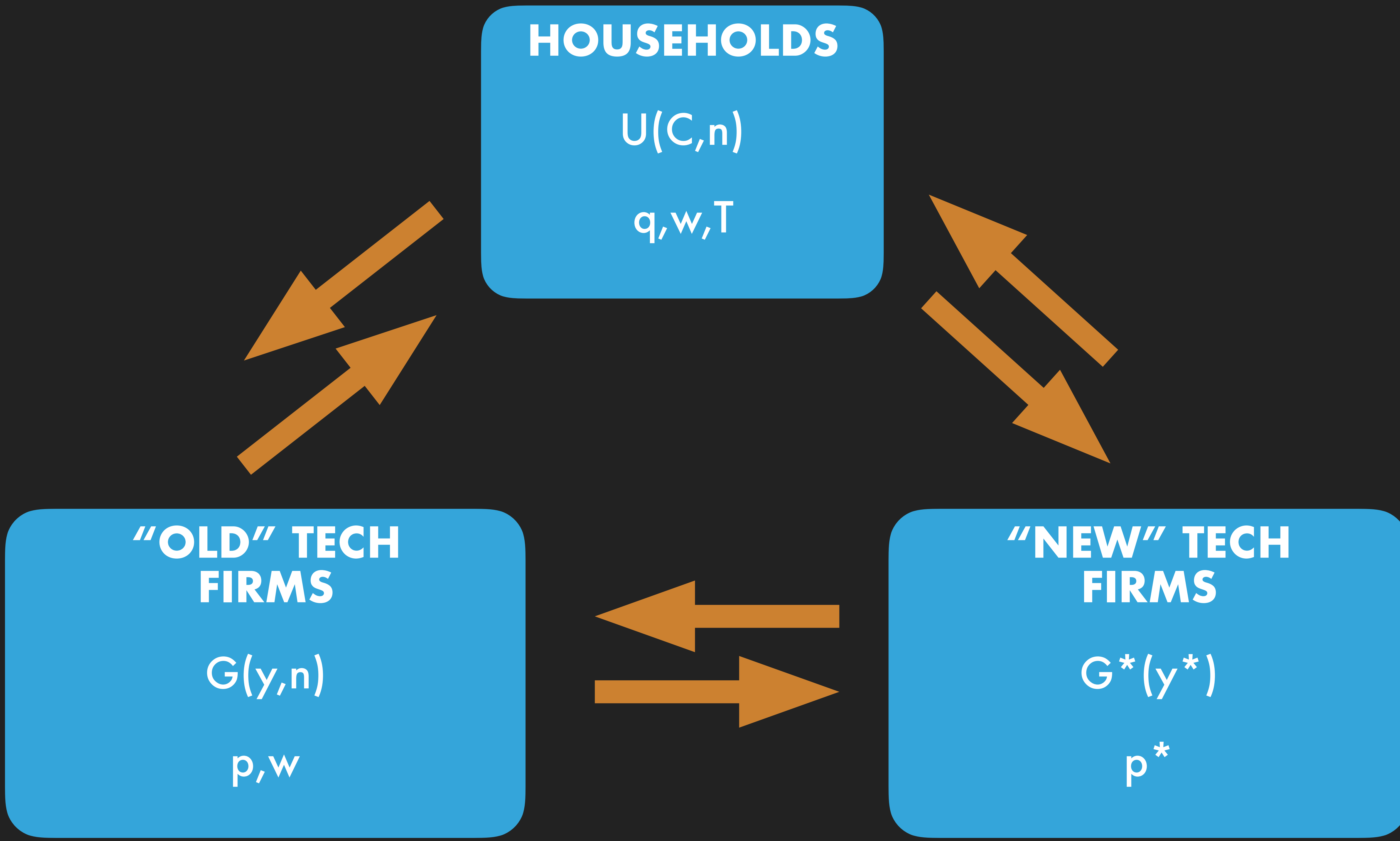

HOUSEHOLDS
U(C,n)
p,w
"OLD" TECH FIRMS
G(y,n)
p,w
"NEW" TECH FIRMS
G*(y*)
p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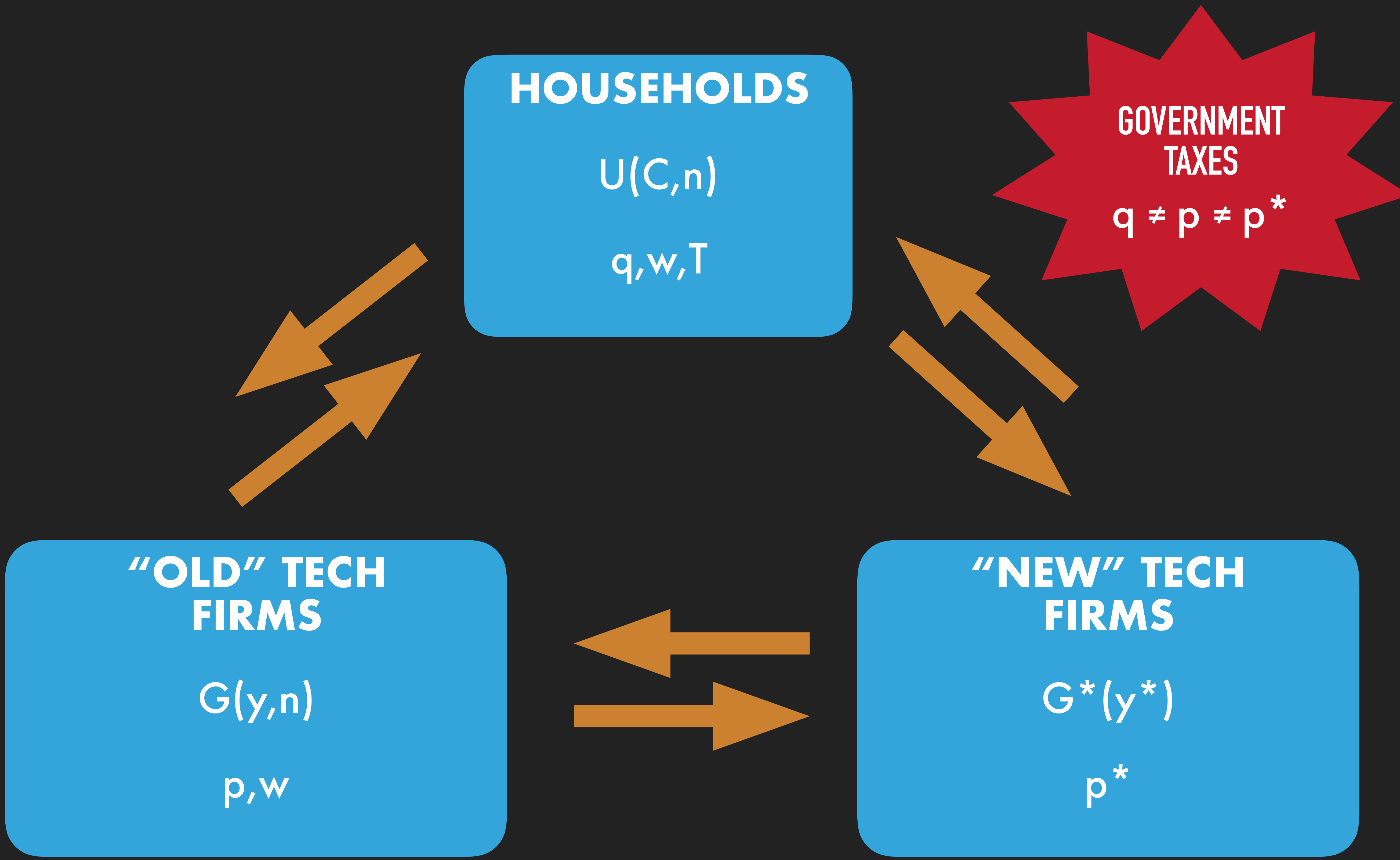
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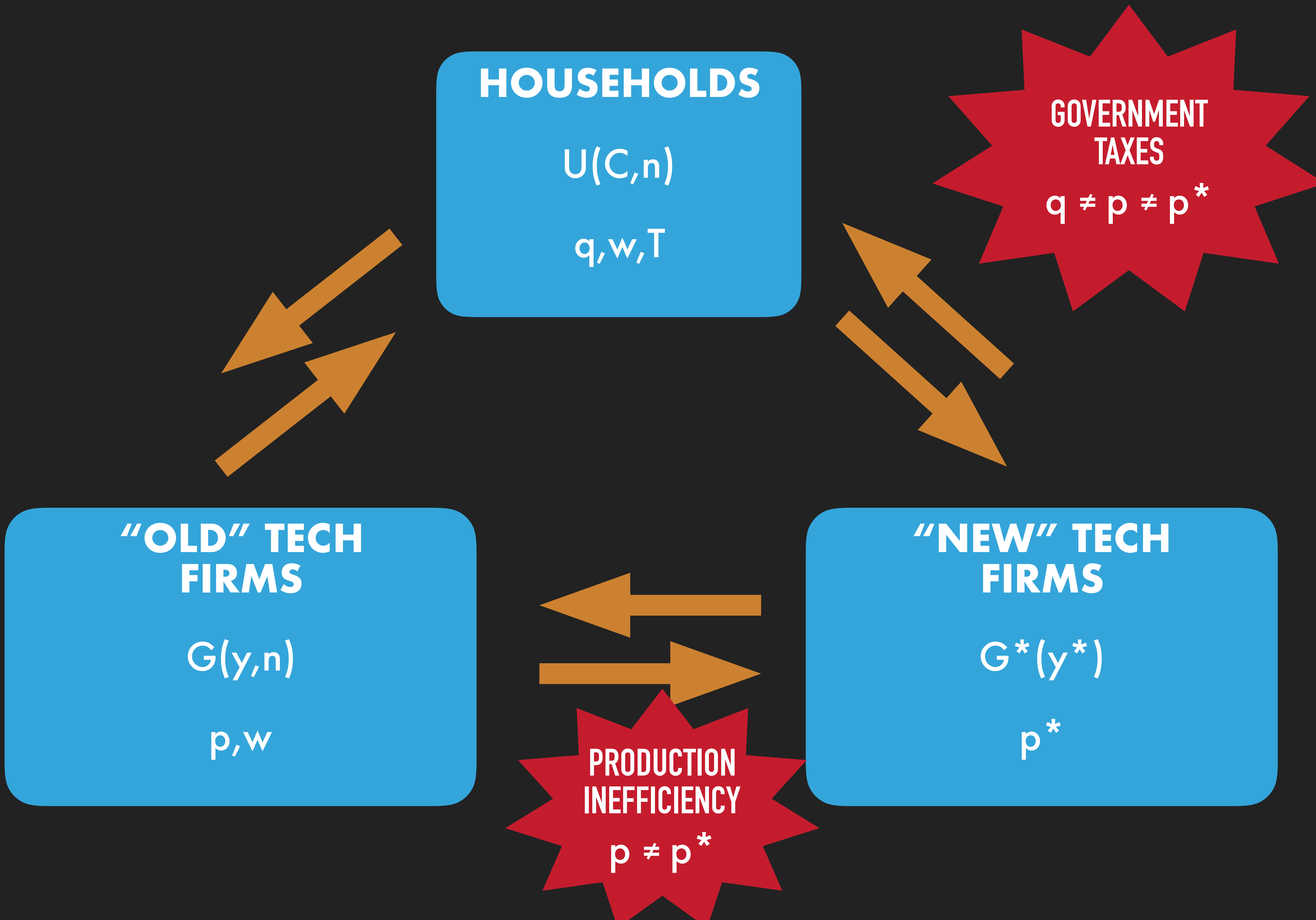
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PRODUCTION INEFFICIENCY
p ≠ p*

EQUILIBRIUM WAGES

- Crucial point…
  - Labor demand

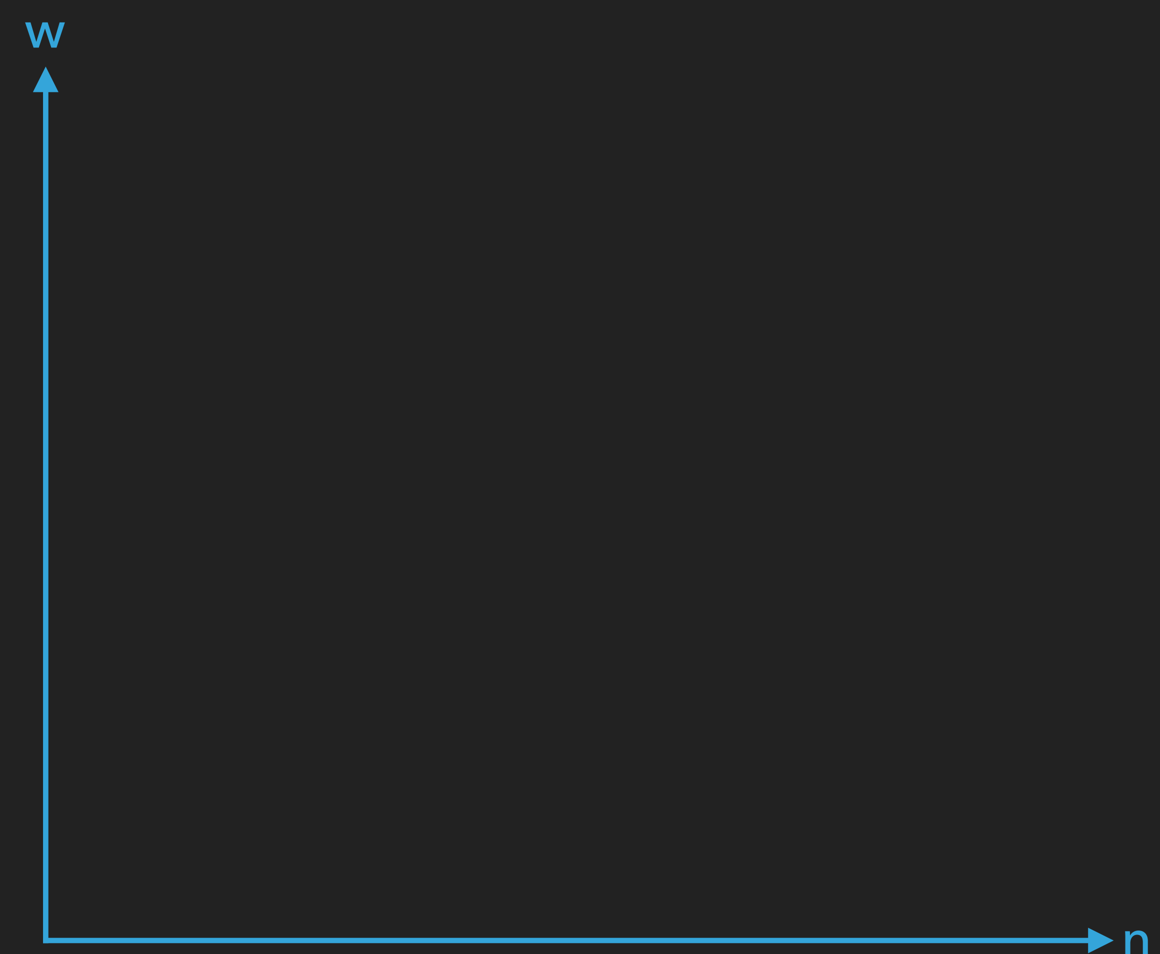
$$n^D(\{w(\theta)\},\{p_i\},\theta)$$

depends on p…

  - Equilibrium wages…

$$w(\{p_i\},\{n(\theta)\},\theta)$$

depend by p
(thus, taxes *t* and *t**)



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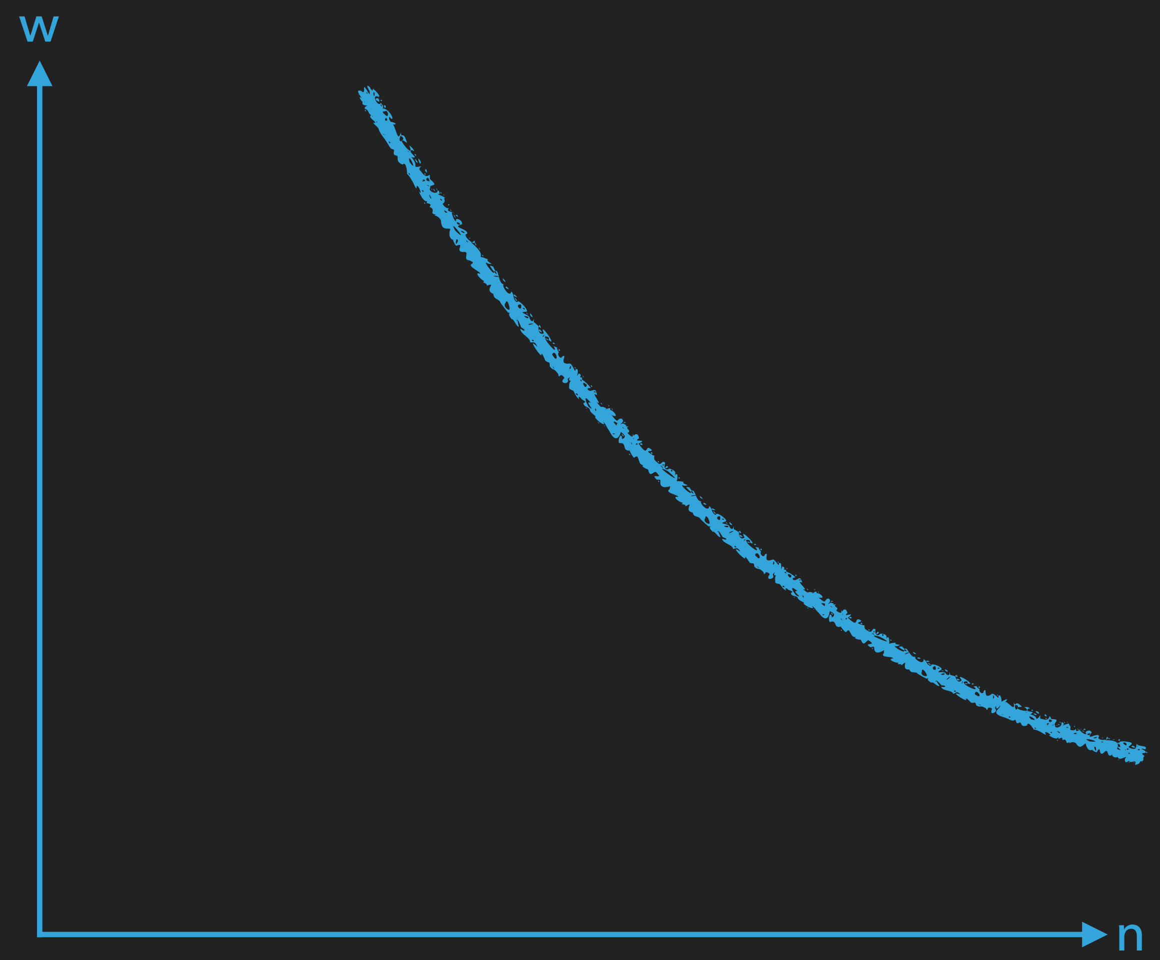

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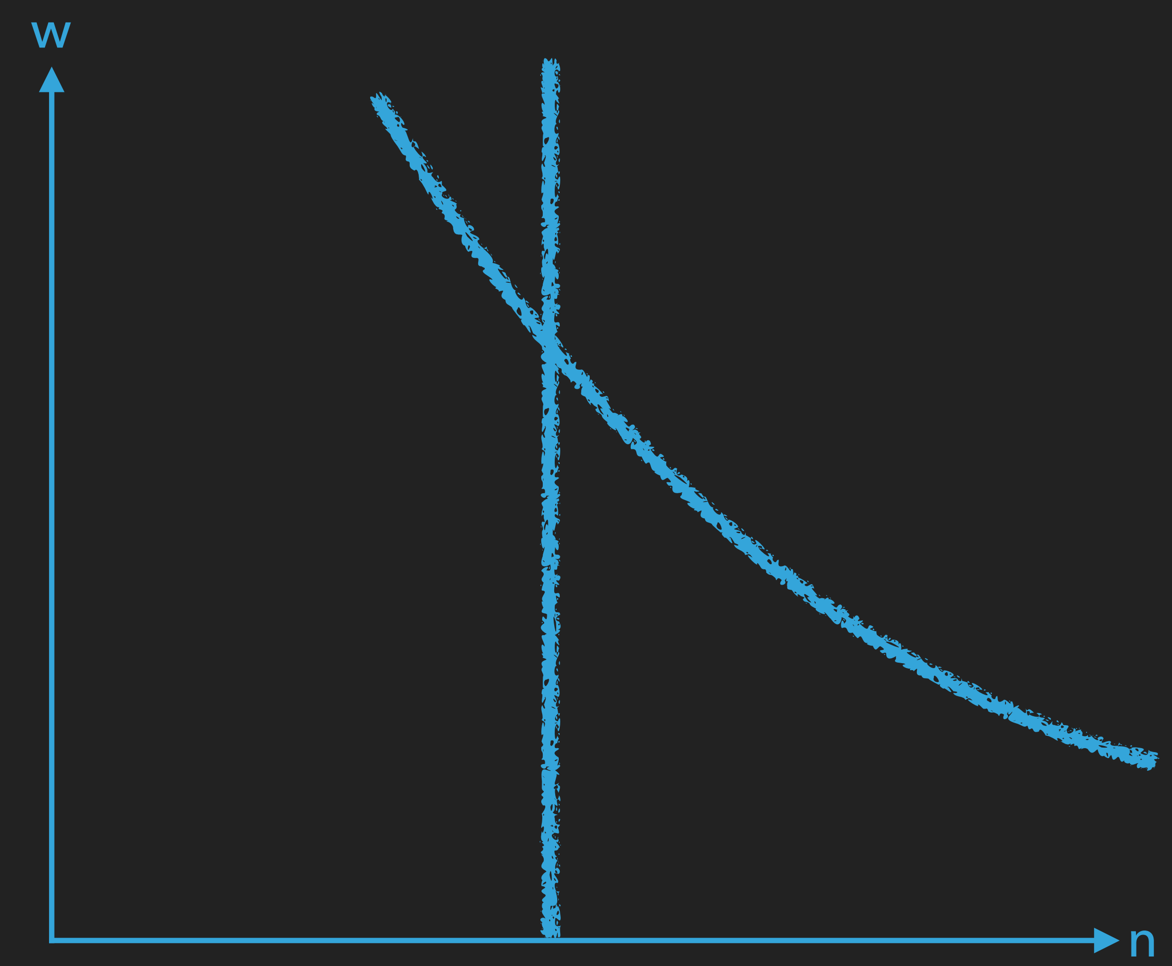

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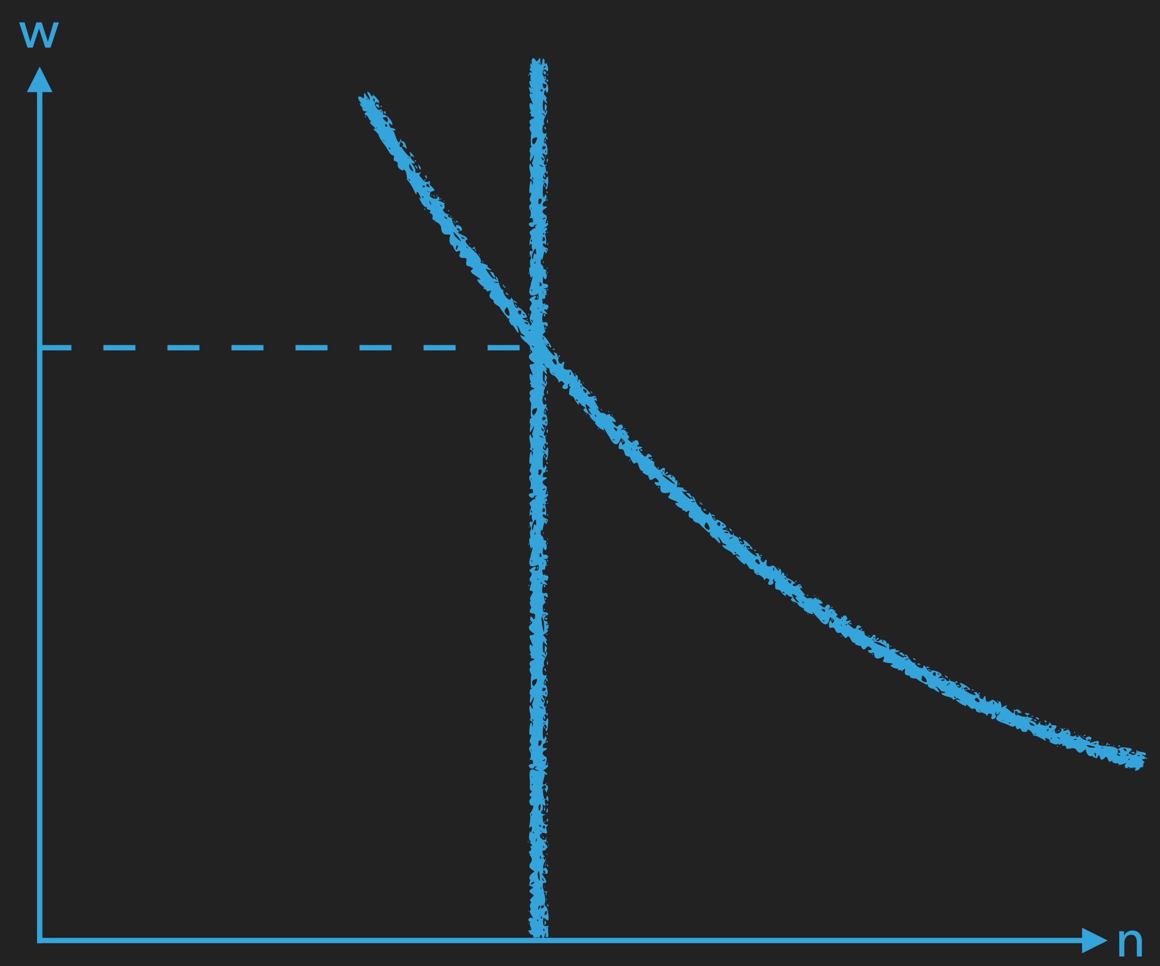

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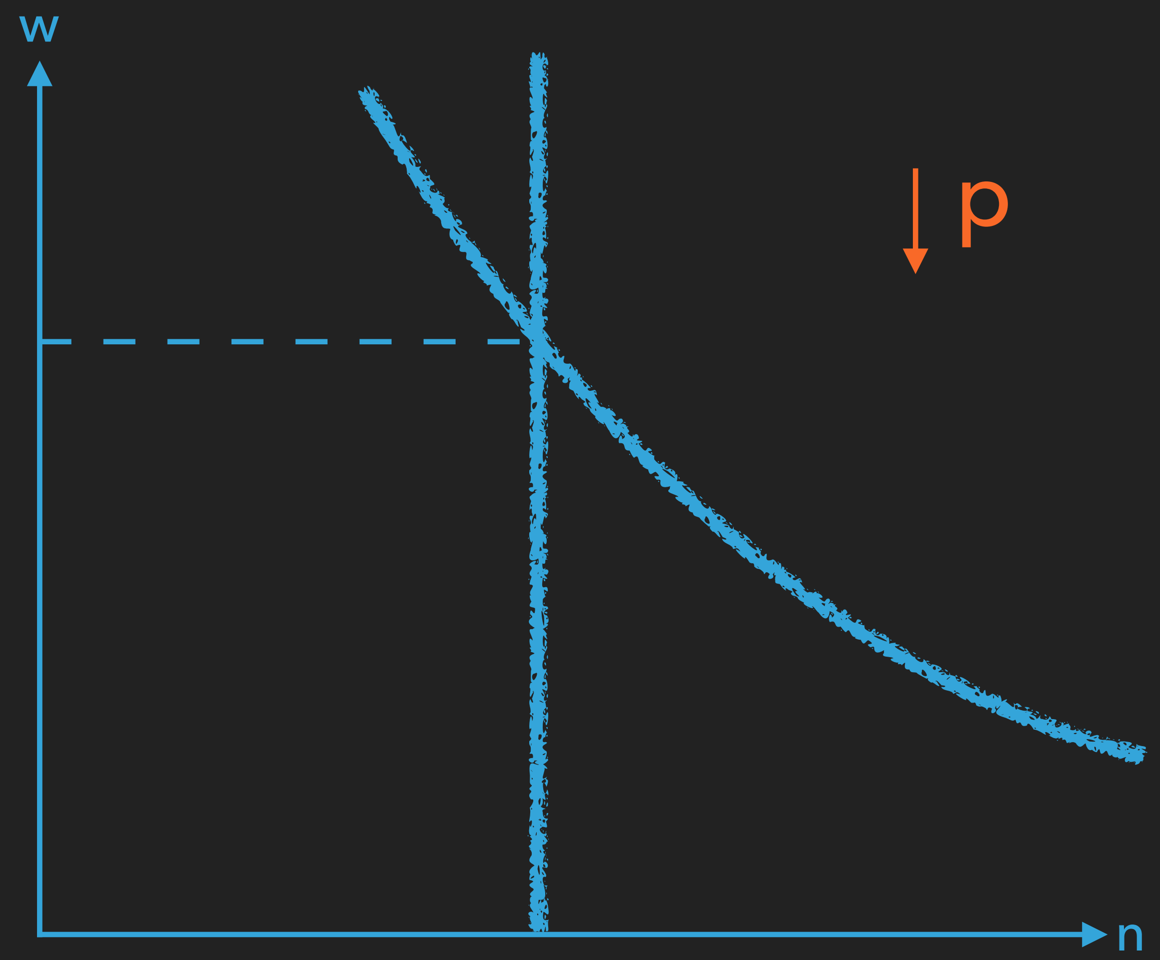

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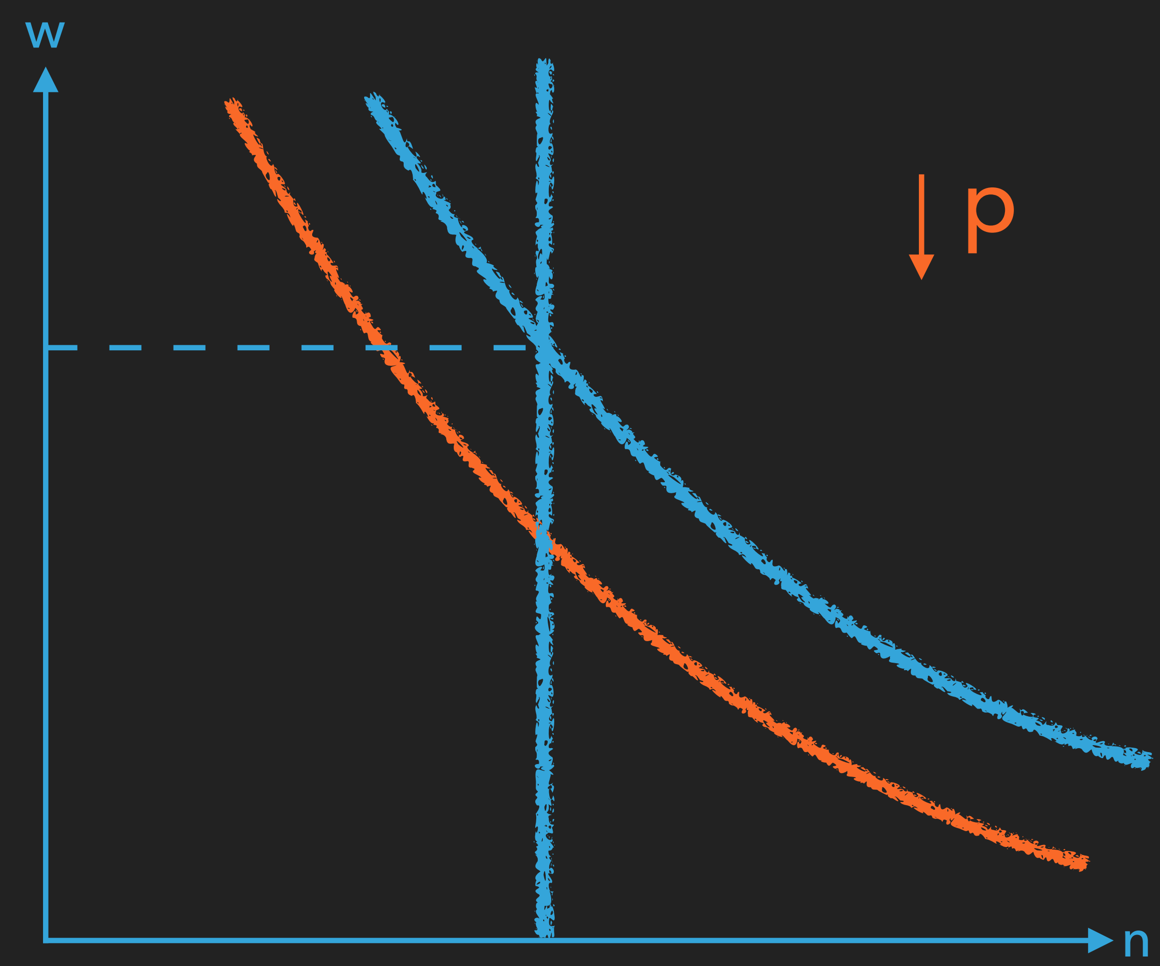

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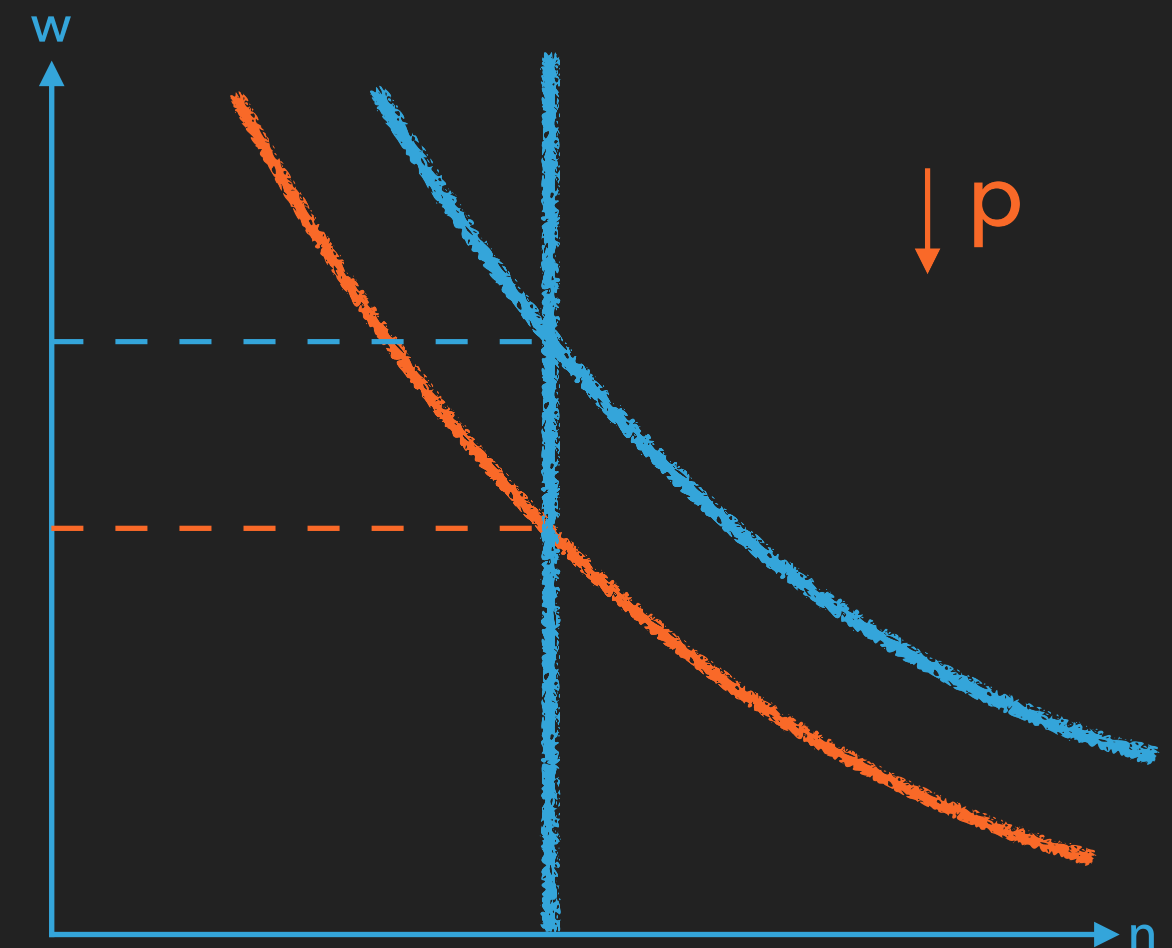

GOVERNMENT

- Chooses competitive equilibrium with taxes to maximize:

$$\int U(\theta) d\Lambda(\theta)$$

- Constraints on taxation of household and old tech firms:

$$\mathcal{R} \equiv \{R(\cdot;\cdot) | R(x;\theta) = x - T(x;\theta) \text{ for some feasible } T(\cdot;\cdot)\}$$

$$\mathcal{P} \equiv \{\{p_i, q_i\} | p_i = q_i/(1 + t_i) \text{ for some feasible } \{t_i\}\}$$

- No constraints on taxation of new tech firms:

$$t_i^* \in [-1, \infty) \text{ for all } i$$

THE GOVERNMENT'S PROBLEM

$$\max_{\{U(\theta)\},\{n(\theta)\},R\in\mathcal{R},\{p_i,q_i\}\in\mathcal{P}} \int U(\theta)d\Lambda(\theta)$$

$$n(\theta), U(\theta) \in \text{argmax}_{n,U}\{U|e(\{q_i\}, C(n,U)) = R(w(\{p_i\},\{n(\theta)\};\theta)n;\theta)\}$$

$$G^*(\{c_j(\{q_i\},\{n(\theta)\},\{U(\theta)\}) - y_j(\{p_i\},\{n(\theta)\})\};\phi) \leq 0$$

VALUATION OF NEW TECHNOLOGIES

TECHNOLOGICAL CHANGE

$$W(\phi) = \max_{\{U(\theta)\},\{n(\theta)\},R\in\mathcal{R},\{p_i,q_i\}\in\mathcal{P}} \int U(\theta)d\Lambda(\theta)$$

$$n(\theta), U(\theta) \in \text{argmax}_{n,U}\{U|e(\{q_i\}, C(n,U)) = R(w(\{p_i\},\{n(\theta)\};\theta)n;\theta)\}$$

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- Envelope…

$$\frac{dW}{d\phi} = \gamma \frac{\partial G^*}{\partial \phi}$$

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- Envelope...

$$\frac{dW}{d\phi} = \gamma \frac{\partial G^*}{\partial \phi}$$

Same as first-best (Solow, Hulten)

No Immiserizing Growth!

PROP 6.

$$dW/d\phi \geq 0 \quad \longleftrightarrow \quad \partial G^*/\partial \phi \leq 0$$

APPLICATION I: TRADE

- Trade shock

$$dW/d\phi > 0 \iff \sum \frac{d\bar{p}_i(\phi)}{d\phi} y_i^* > 0$$

- China Shock good or bad depends on TOT effect alone
  - Same as in First-Best…
  - Good iff it raises value of net exports at initial quantities
- Gain from Trade = Integral below import demand!

APPLICATION II: INNOVATION

- Suppose new tech firms may also choose technology:

$$\{y_i^*, \phi^*\} \in \arg \max_{\{\tilde{y}_i\}, \phi \in \bar{\Phi}} \{\sum p_i^* \tilde{y}_i | G^*(\{\tilde{y}_i\}; \phi) \leq 0\}$$

- Government can restrict innovation: $\bar{\Phi} \subset \Phi$
- Envelope result ⇒ optimal technology satisfies:

$$\frac{\partial G^*(\{y_i^*\}; \phi^*)}{\partial \phi} = 0$$

- FOC of unconstrained firm ⇒ No restriction on innovation

OPTIMAL TAXATION

2ND WELFARE THEOREM

- **Lump-sum taxes**

$$T(w(\theta)n(\theta);\theta) = T(\theta)$$

2ND WELFARE THEOREM

- **Lump-sum taxes**

$$T(w(\theta)n(\theta);\theta) = T(\theta)$$

  - **At the Optimum:**
    - Zero taxes: $p = p^* = q$

DIAMOND-MIRRLEES (1971), DIXIT-NORMAN (1985)

- **Linear taxation**

$$T(w(\theta)n(\theta);\theta) = \tau(\theta)w(\theta)n(\theta)$$

- **The government's problem**

$$\max_{\{U(\theta)\},\{n(\theta)\},\{p_i,q_i\},\{r(\theta)\}} \int U(\theta)d\Lambda(\theta)$$

$$n(\theta), U(\theta) \in \text{argmax}_{n,U}\{U|e(\{q_i\}, C(n,U)) = r(\theta)n\}$$

$$G^*(\{c_j(\{q_i\},\{n(\theta)\},\{U(\theta)\}) - y_j(\{p_i\},\{n(\theta)\})\};\phi) \leq 0$$

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- **At the Optimum**
  - Same taxes on old and new tech: $p = p^*$
  - Production efficiency: Free trade; No tax on robots

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Surprising! Why?

DIAMOND-MIRRLEES (1971), DIXIT-NORMAN (1985)

- **Linear taxation**

$$T(w(\theta)n(\theta);\theta) = \tau(\theta)w(\theta)n(\theta)$$

Key: complete tax system controls after-tax wages

- **The government's problem**

$$\max_{\{U(\theta)\},\{n(\theta)\},\{p_i,q_i\},\{r(\theta)\}} \int U(\theta)d\Lambda(\theta)$$

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- **At the Optimum**
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Surprising! Why?

THIS PAPER

- **Non-linear income taxation**

$$T(w(\theta)n;\theta) = T(w(\theta)n) \text{ for all } \theta$$

- **The government's problem**

$$\max_{\{U(\theta)\},\{n(\theta)\},\{p_i,q_i\}\in\mathcal{P}} \int U(\theta)d\Lambda(\theta)$$

$$U(\theta) = \max_{\theta'} u\left(C(n(\theta'),U(\theta')), n(\theta')\frac{w(\{p_i\},\{n(\theta)\};\theta')}{w(\{p_i\},\{n(\theta)\},\theta)}\right)$$

$$G^*(\{c_j(\{q_i\},\{n(\theta)\},\{U(\theta)\}) - y_j(\{p_i\},\{n(\theta)\})\};\phi) \leq 0$$

THIS PAPER

- **Non-linear income taxation**

$$T(w(\theta)n;\theta) = T(w(\theta)n) \text{ for all } \theta$$

incomplete labor tax

- **The government's problem**

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THE GOVERNMENT'S PROBLEM

$$\max_{\{U(\theta)\},\{n(\theta)\},\{p_i,q_i\}\in\mathcal{P}} \int U(\theta)d\Lambda(\theta)$$

$$U'(\theta) = -u_n(C(n(\theta),U(\theta)),n(\theta))n(\theta)\omega(\{p_i\},\{n(\theta)\};\theta)$$

$$G^*(\{c_j(\{q_i\},\{n(\theta)\},\{U(\theta)\}) - y_j(\{p_i\},\{n(\theta)\})\};\phi) \leq 0$$

with:

$$\omega(\{p_i\},\{n(\theta)\};\theta) \equiv \frac{w_\theta(\{p_i\},\{n(\theta)\};\theta)}{w(\{p_i\},\{n(\theta)\};\theta)}$$

OPTIMAL TAXES

PROP 1. Taxes on <u>both</u> old and new technology

$$t^* = 0$$

$$D_p y \cdot (\frac{tq}{1+t}) = \int (\Lambda(\theta) - F(\theta))(1 - \tau(\theta))x(\theta)(\nabla_p \omega(\theta))dF(\theta)$$

- Intuition: LHS cost = RHS benefit
  - LHS = cost traditional Harberger triangle
  - RHS = benefit of manipulating pre-tax wages
- Sufficient Statistics…
  - marginal impact on wage $\nabla_p \omega(\theta)$ observable in principle
  - details of production function structure, irrelevant!

FROM THEORY TO PRACTICE: AN ILLUSTRATION

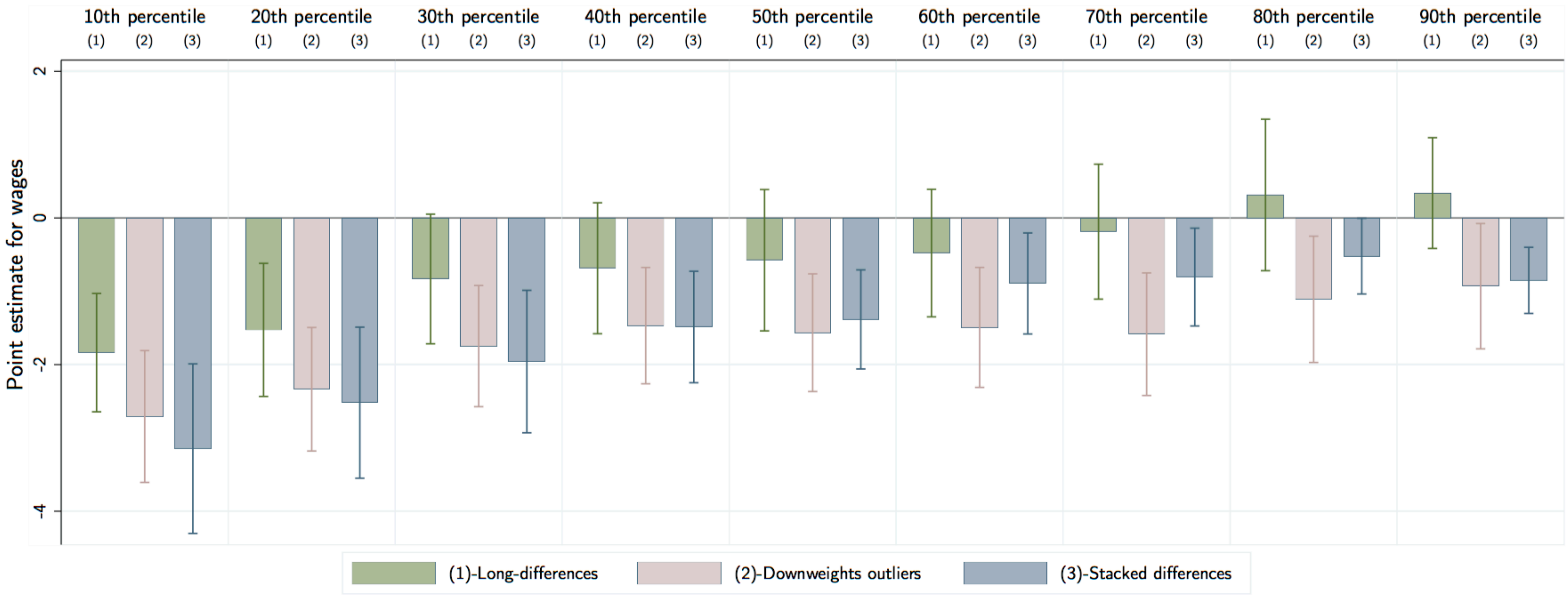

FIGURE 13: RELATIONSHIP BETWEEN THE EXPOSURE TO ROBOTS AND THE WAGE DISTRIBUTION.

Note: The figure shows the estimates of the change in the 10th, 20th, . . . , and 90th wage deciles against the (exogenous) exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The green bars correspond to a long-differences specification similar to column 4 of Table 2; The rose bars correspond to a long-differences specification similar to column 6 of Table 2, in which we downweigh outliers; the blue bars correspond to a stacked-differences specification similar to column 2 of Table 3.

Acemoglu and Restrepo (2017)

OPTIMAL TAXES (CONTINUED)

PROP 2. Taxes <u>only</u> on new technology $(t = 0)$

$$(D_q c - D_p y) \cdot (\frac{pt^*}{1+t^*}) = \int (\Lambda(\theta) - F(\theta))(1 - \tau(\theta))x(\theta)(\nabla_p \omega(\theta))dF(\theta)$$

- Trade case:
  - No production taxes; only trade taxes on the table
  - Mayer and Riezman (87) vs. Grossman and Helpman (94)

CORRELATIONS AND BOUNDS

- What goods do we tax more?

COROL 1. **Optimal distortion between old and new technology**

$$(p^* - p)' \cdot \int (\Lambda(\theta) - F(\theta))(1 - \tau(\theta))x(\theta)(\nabla_p \omega(\theta))dF(\theta) \geq 0$$

- What can we say if we do not know Pareto weights?

COROL 2. **Taxes on both old and new technology**

$$D_{p_i} y \cdot (\frac{tq}{1+t}) \leq \int [\mathbf{1}_{\Theta_i^+}(\theta) - \mathbf{1}_{\Theta_i^-}(\theta) F(\theta)](1 - \tau(\theta))x(\theta)\omega_{p_i}(\theta)dF(\theta)$$

$$D_{p_i} y \cdot (\frac{tq}{1+t}) \geq \int [\mathbf{1}_{\Theta_i^-}(\theta) - \mathbf{1}_{\Theta_i^+}(\theta) F(\theta)](1 - \tau(\theta))x(\theta)\omega_{p_i}(\theta)dF(\theta)$$

APPLICATION

A SIMPLE ENVIRONMENT

- Households

$$U = c - h(n)$$

- New tech firms produce robots

$$r^* = \phi y^*$$

- Old tech firms use robots and labor to produce final good

$$y = \int y(r(\theta), n(\theta); \theta) dF(\theta)$$

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→ well-known "Stiglitz" effects

(Scheuer-Rotschild, Ales-Kurnaz-Sleet)

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our focus

well-known "Stiglitz" effects
(Scheuer-Rotschild, Ales-Kurnaz-Sleet)

OPTIMAL TAX ON ROBOTS

PROP 3. Optimal tax on robots

$$\frac{t_r^*}{1+t_r^*} = \frac{\int \frac{\epsilon(\theta)}{\epsilon(\theta)+1} \cdot \eta(\theta) \cdot \tau(\theta) \cdot \frac{1-s_r(\theta)}{s_r(\theta)} \cdot g_r(\theta) dF(\theta)}{\rho(p_r) - \int \frac{\epsilon(\theta)}{\epsilon(\theta)+1} \cdot \eta(\theta) \cdot g_r(\theta) dF(\theta)}$$

...everything observable!

$$g_r(\theta) \equiv \frac{r(p_r, n(\theta); \theta)}{r(p_r, \{n(\theta)\})}$$

$$s_r(\theta) \equiv \frac{p_r r(p_r, n(\theta); \theta)}{p_r r(p_r, n(\theta); \theta) + w(\theta) n(\theta)}$$

$$\epsilon(\theta) \equiv \frac{d \ln(n(\theta))}{d \ln h(n(\theta)))}$$

$$\rho \equiv \frac{\partial \ln r(p_r, \{n(\theta)\})}{\partial \ln p_r}$$

$$\eta(\theta) \equiv \frac{\partial \ln \omega(p_r; \theta)}{\partial \ln p_r}$$

TWO RESULTS

- Two uses of this formula
- Compute tax using formula…
  - input from Acemoglu-Restrepo estimates
  - no further structure
- Comparative static result…
  - how does optimal tax vary as robots get better?
  - more structure imposed

COMPARATIVE STATICS UNDER PARAMETRIC RESTRICTIONS

- Rawlsian preferences

$$\Lambda(\theta) = 1 \text{ for all } \theta$$

- Iso-elastic labor supply

$$h(n) = \frac{n^{1+1/\epsilon}}{1+1/\epsilon}$$

- Cobb-Douglas production functions

$$y(r,n;\theta) = \exp(\alpha(\theta)) \cdot \left(\frac{r}{\beta(\theta)}\right)^{\beta(\theta)} \left(\frac{n}{1-\beta(\theta)}\right)^{1-\beta(\theta)}$$

- With $\alpha(\theta)$ $\beta(\theta)$ such that Pareto distribution of wages

$$w(p_r;\theta) = (1-\theta)^{-1/\gamma(p_r)}$$

A SIMPLE TAX FORMULA

PROP 4. Optimal tax on robots

$$\frac{t_r^*}{1+t_r^*} = \frac{\Phi}{\rho - \Phi}\frac{1-s_r}{s_r}$$

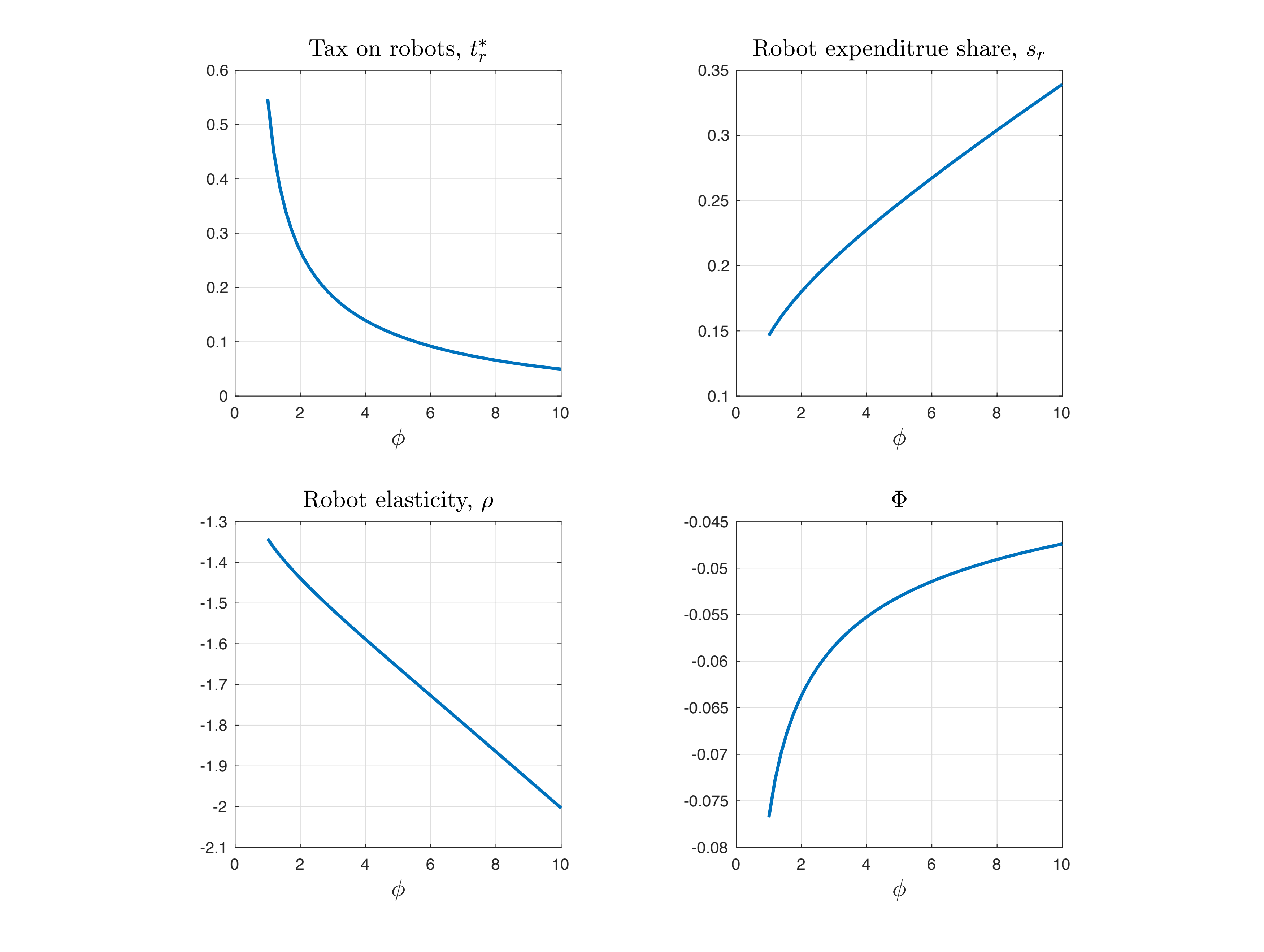
$$\Phi \equiv -\frac{\epsilon\beta\gamma(p_r)}{(\epsilon+1)+\epsilon\gamma(p_r)}$$

$$s_r \equiv \frac{\int p_r r(p_r, n(\theta);\theta)dF(\theta)}{\int (p_r r(p_r, n(\theta);\theta) + w(\theta)n(\theta))dF(\theta)}$$

CHEAPER ROBOTS, LESS LUDDISM

PROP 5.

Optimal tax decreasing with robot-makers' productivity.



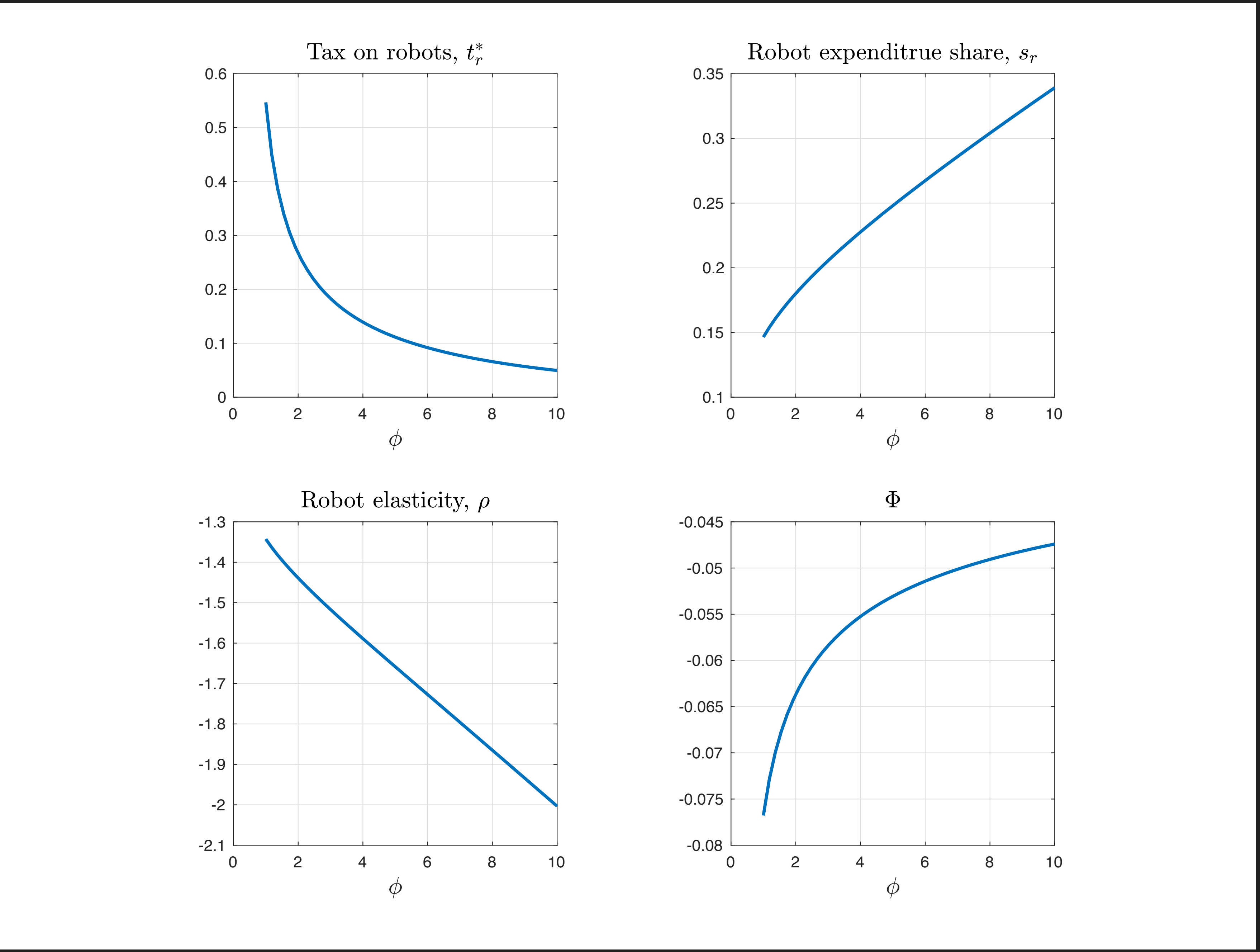
CHEAPER ROBOTS, LESS LUDDISM

IMPORTS PROTECTIONISM

PROP 5.

Optimal tax decreasing with robot-makers' productivity.

foreign



USING FORMULA

- Tentative: implement formula with Acemoglu-Restrepo
- After rearranging…

$$\frac{t_r^*}{1+t_r^*} \geq \frac{wn}{p_r r} \int \frac{\epsilon(\theta)}{\epsilon(\theta)+1} \cdot \tau(\theta) \cdot \frac{w(\theta)n(\theta)}{wn} \cdot \frac{d\omega(\theta)}{d\log r}\, d\theta$$

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Acemoglu-Restrepo

FROM THEORY TO PRACTICE: AN ILLUSTRATION

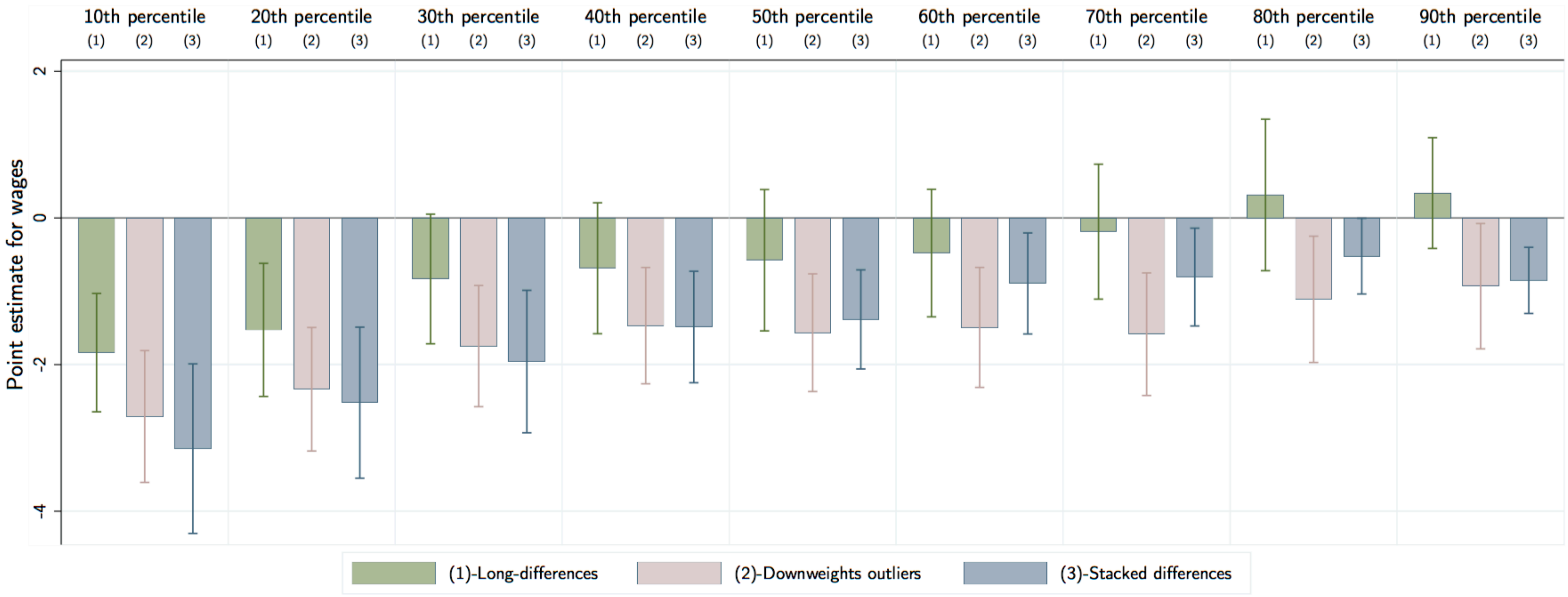

FIGURE 13: RELATIONSHIP BETWEEN THE EXPOSURE TO ROBOTS AND THE WAGE DISTRIBUTION.

Note: The figure shows the estimates of the change in the 10th, 20th, . . . , and 90th wage deciles against the (exogenous) exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The green bars correspond to a long-differences specification similar to column 4 of Table 2; The rose bars correspond to a long-differences specification similar to column 6 of Table 2, in which we downweigh outliers; the blue bars correspond to a stacked-differences specification similar to column 2 of Table 3.

Acemoglu and Restrepo (2017)

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Acemoglu-Restrepo

- Implication…
  - high taxes on Robots
  - with high labor elasticity: tax is infinite
  - intuition: tiny share, but impactful on distribution!

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Acemoglu-Restrepo
non-trivial

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Guner-Ventura

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NIPA
~250

Acemoglu-Restrepo
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CONCLUDING REMARKS

SUMMARY

1. When is technological change welcomed?
    - Like in a first best world (despite not being first best)
2. How should government policy respond?
    - Formulas/bounds as functions of shares & elasticities
    - More robots and more trade may go hand in hand with more inequality and lower taxes on robots and trade
    - No rationale for taxing/subsidizing innovation

- Next: other applications (Krusell-Ohanian-RiosRull-Violante)