JOBS AND TECHNOLOGY IN GENERAL EQUILIBRIUM: A THREE-ELASTICITIES APPROACH

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Background and purpose

Background

- Much research has been done on the links between technology and jobs, mostly empirical, but also theoretical contributions.
- The theoretical framework has most often
  - Been partial equilibrium or multi-sector models with limited GE feedback effects;
  - Focussed on trade-offs between job-destroying substitution effects and job-creating demand effects within a sector;
  - Not captured factor-market interaction between sectors.

The purpose of the paper is to demonstrate that general equilibrium matters

- The interaction between the nature of technical shock(s) and the nature of the sector(s) in which they occur determines the labour-market outcomes.
- The results may be profoundly different from what a partial equilibrium framework would predict.

Preliminaries – one- and two-elasticity approaches

One-sector, two-factor models – one elasticity:

- Assume: Factors A and B. Elasticity of substitution σ. Factor augmentation for factor A.
- Relative wage effect given by elasticity of substitution alone:
  - ✓ $sign\left(\widehat{w}_A - \widehat{w}_B\right) = sign\,(\sigma - 1)$, i.e. factor-saving ($\sigma < 1$) versus factor-using ($\sigma > 1$) effect.
- A reference: The canonical model of Acemoglu and Autor (2011).

Two-sector, two-factor models – two elasticities:

- Assume:
  - ✓ Factor A: robots, factor B: labour.
  - ✓ Sectors interact in goods market (demand elasticity ε) and labour market.
- What happens to wage and employment in sector 1 when robots become more efficient?
  - ✓ $sign\,(\widehat{w}_B) = sign\,(\varepsilon - \sigma)$
  - ✓ $sign\left(\hat{L}_{B1}\right) = sign(\varepsilon - \sigma)$ (provided the labour supply to sector 1 increases with the wage rate)
- A reference: Graetz and Michaels (2018).

Related literature

- Jones (1965 and 2000) studies technical change in a Heckscher-Ohlin model, but models technical progress in a different way from ours, and focusses only on wage effects.
- Xu (2000) goes through a catalogue of factor-augmentation cases, focussing on relative wage effects.
- Haskel and Slaughter (2002) study the effects of skill-biased technical change (SBTC) on skill premia in a model similar to ours. However, they model SBTC as an exogenous increase in the share of skilled labour in the production function.
- Acemoglu and Restrepo (2018, 2019) model technical progress in a task-based, one-sector framework, where some tasks performed by labour are automated, while new labour-using tasks emerge.
- Graetz and Michaels (2018) and Autor and Dorn (2013) model technical progress as a fall in the price of robots/computers, resulting in variants of a 2-elaticity approach.

General equilibrium framework

- 2x2 Heckscher-Ohlin model, with factors $f = A, B,$ and sectors $s = 1{,}2.$
- Technology enters as factor-augmenting technical change.
- Production and unit cost functions given by $X_s = F_s(\alpha_{As}L_{As}, \alpha_{Bs}L_{Bs})$; $C_s(w_A/\alpha_{As}, w_B/\alpha_{Bs})$
- Relative demand given by $X_1/X_2 = (p_1/p_2)^{-\varepsilon}$
- We use hat algebra with the following equilibrium conditions

$$\hat{p}_s = \omega_s(\hat{w}_A - \hat{\alpha}_{As}) + (1-\omega_s)(\hat{w}_B - \hat{\alpha}_{Bs}), \qquad s = 1{,}2$$

$$\hat{X}_s = \omega_s\left(\hat{L}_{As} + \hat{\alpha}_{As}\right) + (1-\omega_s)\left(\hat{L}_{Bs} + \hat{\alpha}_{Bs}\right), \qquad s = 1{,}2$$

$$\upsilon_f \hat{L}_{f1} + \left(1-\upsilon_f\right)\hat{L}_{f2} = \hat{L}_f = 0, \qquad f = A, B$$

$$\hat{X}_1 - \hat{X}_2 = -\varepsilon(\hat{p}_1 - \hat{p}_2)\ .$$

- Elasticity of substitution (measured in efficiency units):

$$\sigma_s \equiv -\left[\frac{(\hat{L}_{As}+\hat{\alpha}_{As})-(\hat{L}_{Bs}+\hat{\alpha}_{Bs})}{(\hat{w}_A-\hat{\alpha}_{As})-(\hat{w}_B-\hat{\alpha}_{Bs})}\right], \qquad s = 1{,}2.$$

- To simplify, we assume $\sigma_1 = \sigma_2 = \sigma$

α_{fs}: efficiency parameter for factor f in sector s.

ω_s: the cost share of factor A in sector s.

υ_f: the share of factor f used in sector 1.

Some definitions

We focus on relative effects and define

	Goods	Factors
Relative prices	$\Delta\hat{p} \equiv \hat{p}_1 - \hat{p}_2$	$\Delta\hat{w} \equiv \hat{w}_A - \hat{w}_B$
Relative quantities	$\Delta\hat{X} \equiv \hat{X}_1 - \hat{X}_2$	$\Delta\hat{L}_f \equiv \hat{L}_{f1} - \hat{L}_{f2}, f = A, B$

Summary measures of the combined effects of technology parameter changes

	Cost-saving effects	Factor-saving effects
In each sector/factor	$\hat{\chi}_s = \omega_s\hat{\alpha}_{As} + (1-\omega_s)\hat{\alpha}_{Bs}$	$\hat{\lambda}_f \equiv \upsilon_f\hat{\alpha}_{f1} + (1-\upsilon_f)\hat{\alpha}_{f2}$
Bias towards sector 1/factor A	$\Delta\hat{\chi} \equiv \hat{\chi}_1 - \hat{\chi}_2$	$\Delta\hat{\lambda} \equiv \hat{\lambda}_A - \hat{\lambda}_B$

- In our analysis, a technical shock is characterised by the sector-bias of cost savings ($\Delta\hat{\chi}$) and the factor-bias of factor savings ($\Delta\hat{\lambda}$).

Key labour market relations; relative wage and employment

- Relative wage effect:

$$\Delta\widehat{w} = \beta_{SS}\left\{\Delta\hat{p} + \Delta\hat{\chi}\right\}$$

Note: with no tech shock: $\Delta\widehat{w} = \beta_{SS}\Delta\hat{p}$, i.e.standard Stolper-Samuelson (SS)

- Relative employment effects:

$$\Delta\hat{L}_f = \Delta\hat{X} + \sigma\Delta\hat{p} + (\sigma - 1)\left(\hat{\alpha}_{f1} - \hat{\alpha}_{f2}\right)$$

where relative production effect is:

$$\Delta\widehat{X} = \beta_{RY}\Delta V + \eta\Delta\hat{p}$$

Note: with endowment shock (no tech shock): $\Delta\hat{X} = \beta_{RY}\left(\hat{L}_A - \hat{L}_B\right) + \eta\Delta\hat{p}$, i.e. Rybczynski (RY)

Where

$\boldsymbol{\beta_{SS}} \equiv \mathbf{1}/(\boldsymbol{\omega_1} - \boldsymbol{\omega_2})$ is the ***Stolper-Samuelson elasticity*** (note: $|\beta_{SS}| > 1$)

$\boldsymbol{\beta_{RY}} \equiv \mathbf{1}/(\boldsymbol{\upsilon_A} - \boldsymbol{\upsilon_B})$ is the ***Rybczynski elasticity*** (note: $|\beta_{RY}| > 1$)

$\Delta\mathbf{V} \equiv \Delta\hat{\boldsymbol{\lambda}} + \boldsymbol{\sigma}(\boldsymbol{\beta_{SS}}\Delta\hat{\boldsymbol{\chi}} - \Delta\hat{\boldsymbol{\lambda}})$ is the "***relative-factor-endowment representation***" of the tech shock.

- ✓ direct effect, $\Delta\hat{\lambda}$, plus substitution effects, $\sigma(\beta_{SS}\Delta\hat{\chi} - \Delta\hat{\lambda})$.
- ✓ equivalent to endowment change, $\left(\hat{L}_A - \hat{L}_B\right)$.

$\boldsymbol{\eta} \equiv \boldsymbol{\sigma}(\boldsymbol{\beta_{RY}}\boldsymbol{\beta_{SS}} - \mathbf{1}) \geq 0$ is the ***relative supply elasticity*** (movement along the production possibility frontier).

Closing the model and closed form labour market effects

Close model by equating relative supply and demand (using $\Delta\widehat{X} = -\varepsilon\Delta\hat{p}$):

$$\Delta\hat{p} = \frac{-\beta_{RY}}{\varepsilon+\eta}\Delta V$$

Using this in the relative wage and employment expressions, closed form solutions are:

$$\Delta\widehat{w} = \frac{-\beta_{SS}\beta_{RY}}{\varepsilon+\eta}\Delta\mathrm{V} + \beta_{SS}\Delta\hat{\chi},$$

$$\Delta\widehat{L}_f = \frac{(\varepsilon-\sigma)\beta_{RY}}{\varepsilon+\eta}\Delta\mathrm{V} + (\sigma-1)\left(\hat{\alpha}_{f1} - \hat{\alpha}_{f2}\right)$$

Roles of elasticities – step-by-step

Illustration 1: Small, open economy ($\Delta\hat{p} = 0$), Leontief technology ($\sigma = 0$):

- ✓ $\Delta\hat{w} = \beta_{SS}\Delta\hat{\chi}$;
- ✓ $\Delta\hat{L}_f = \beta_{RY}\Delta\hat{\lambda} - (\hat{\alpha}_{f1} - \hat{\alpha}_{f2}),\ f = A, B$

➢ RESULT: Impact depends on sector and/or factor bias of the shock (as per the cost bias $\Delta\hat{\chi}$ and factor bias $\Delta\hat{\lambda}$) and their interactions with the factor-intensity of the sector in which the tech shock is focused (as per β_{SS}, β_{RY})

Illustration 2: Generalising

➢ $\Delta\hat{p} \neq 0, \sigma = 0$: Affects relative wages, but not quantities (production and employment).

➢ $\Delta\hat{p} \neq 0, \sigma > 0$: Affects relative wages, production and employment.

General case: focus on technical shocks

Recall the general labour market impacts:

$$\Delta\hat{w} = \frac{-\beta_{SS}\beta_{RY}}{\varepsilon+\eta}\Delta V + \beta_{SS}\Delta\hat{\chi}, \qquad \Delta\hat{L}_f = \frac{(\varepsilon-\sigma)\beta_{RY}}{\varepsilon+\eta}\Delta V + (\sigma-1)\left(\hat{\alpha}_{f1} - \hat{\alpha}_{f2}\right)$$

These depend on nature of the shocks as measured by three collections of the underlying augmentations, $\hat{\alpha}_{fs}$: $\Delta\hat{\lambda}$, $\Delta\hat{\chi}$, and ΔV, where $\Delta V \equiv \Delta\hat{\lambda} + \sigma(\beta_{SS}\Delta\hat{\chi} - \Delta\hat{\lambda})$

Note: σ affects prices and quantities indirectly through its impact on ΔV, in addition to the direct effect on relative employment through $(\sigma - 1)$, the factor-saving versus factor-using effect.

For specific technology shocks, we can sign these.

Illustrating mechanism with special-case technology shocks

Case 1 (sector-specific): $\hat{\alpha}_{A1} = \hat{\alpha}_{B1} = \hat{\alpha}_1 > 0;\ \hat{\alpha}_{A2} = \hat{\alpha}_{B2} = 0.$

- Sector-1 biased cost-saving effect: $\Delta\hat{\chi} = \hat{\alpha}_1 > 0$
- Factor-A biased factor-saving effect: $\Delta\hat{\lambda} = (\upsilon_A - \upsilon_B)\hat{\alpha}_1 = \hat{\alpha}_1/\beta_{RY} > 0$
- Relative factor endowment representation: $\Delta V = (1+\eta)\hat{\alpha}_1/\beta_{RY} > 0$

To be concrete, suppose sector-1 is A-intensive, so $\boldsymbol{\beta_{RY}, \beta_{SS} > 0}$

Hence, the labour market effects are:

$\Delta\hat{w} = \beta_{SS}\left\{\frac{\varepsilon-1}{\varepsilon+\eta}\right\}\hat{\alpha}_1.$ Sign depends on $\boldsymbol{\beta_{SS}(\varepsilon-1)}$.

$\Delta\hat{L}_A = \Delta\hat{L}_B = \frac{\sigma+\eta}{\varepsilon+\eta}(\varepsilon-1)\hat{\alpha}_1.$ Sign depends on $(\boldsymbol{\varepsilon-1})$.

- ✓ NOTE: Small, open economy (SOE)-case:
  $\Delta\hat{w} = \beta_{SS}\hat{\alpha}_1;\quad \Delta\hat{L}_A = \Delta\hat{L}_B = \sigma\beta_{SS}\beta_{RY}\hat{\alpha}_1$

So if demand is elastic, the cost-saving aspect of technology has a SS-like impact on relative wages, while relative employment is determined by the sector specificity.

Special-case technology shocks (cont'd)

Case 2 (factor-specific): $\hat{\alpha}_{A1} = \hat{\alpha}_{A2} = \hat{\alpha}_A > 0;\ \ \hat{\alpha}_{B1} = \hat{\alpha}_{B2} = 0$

- Sector-1 biased cost-saving effect: $\Delta\hat{\chi} = \hat{\alpha}_A / \beta_{SS} > 0$
- Factor-A biased factor-saving effect: $\Delta\hat{\lambda} = \hat{\alpha}_A > 0$
- Relative factor endowment representation: $\Delta V = \hat{\alpha}_A > 0$.

To be concrete, suppose sector-1 is A-intensive, so $\boldsymbol{\beta_{Ry}, \beta_{SS} > 0}$

Hence the labour-market effects are:

$\Delta\hat{w} = \left[\frac{\varepsilon - 1 + (\sigma-1)\eta/\sigma}{\varepsilon + \eta}\right]\hat{\alpha}_A$. Positive for high values of $\boldsymbol{\varepsilon}$ **and** $\boldsymbol{\sigma}$, negative for low values.

$\Delta\hat{L}_A = \Delta\hat{L}_B = \frac{(\varepsilon - \sigma)\beta_{RY}}{\varepsilon + \eta}\hat{\alpha}_A$. Sign depends on $(\boldsymbol{\varepsilon - \sigma})\boldsymbol{\beta_{RY}}$. i.e. all three elasticities.

- ✓ NOTE: SOE-case: $\Delta\hat{w} = \hat{\alpha}_{\mathrm{A}}$; $\quad \Delta\hat{L}_A = \Delta\hat{L}_B = \beta_{RY}\hat{\alpha}_{\mathrm{A}}$

So for sufficiently high demand elasticity, the relative wage effect is given by factor specificity, while there is a RY-like impact on relative employment.

Sector- and factor-specific cases, compared

	Sector-1 augmenting			Factor-A augmenting	
Relative factor intensity	Sector 1: A-intensive $\beta_{RY}, \beta_{SS} > 0$	Sector 1: B-intensive $\beta_{RY}, \beta_{SS} < 0$		Sector 1: A-intensive $\beta_{RY}, \beta_{SS} > 0$	Sector 1: B-intensive $\beta_{RY}, \beta_{SS} < 0$
$\varepsilon < 1$	$\Delta\widehat{L_A} = \Delta\widehat{L_B} < 0$		$\varepsilon < \sigma$	$\Delta\widehat{L_A} = \Delta\widehat{L_B} < 0$	$\Delta\widehat{L_A} = \Delta\widehat{L_B} > 0$
$\varepsilon < 1$	$\Delta\widehat{w} < 0$	$\Delta\widehat{w} > 0$	$\varepsilon < \beta_{RY}\beta_{SS} - \sigma(\beta_{RY}\beta_{SS} - 1)$	$\Delta\widehat{w} < 0$	
$\varepsilon > 1$	$\Delta\widehat{L_A} = \Delta\widehat{L_B} > 0$		$\varepsilon > \sigma$	$\Delta\widehat{L_A} = \Delta\widehat{L_B} > 0$	$\Delta\widehat{L_A} = \Delta\widehat{L_B} < 0$
$\varepsilon > 1$	$\Delta\widehat{w} > 0$	$\Delta\widehat{w} < 0$	$\varepsilon > \beta_{RY}\beta_{SS} - \sigma(\beta_{RY}\beta_{SS} - 1)$	$\Delta\widehat{w} > 0$	

Employment effects: Sector-bias and $\varepsilon - 1$.

Wage effects: Sector-bias, β_{SS}, and $\varepsilon - 1$.

Employment effects: Factor-bias, β_{RY}, and $\varepsilon - \sigma$.

Wage effects: Factor-bias, and $\varepsilon + \sigma$.

Sector-factor-specific technical progress

Case 3: Augmentation of the intensive factor in sector 1: $\hat{\boldsymbol{\alpha}}_{\boldsymbol{A1}}$>0, all other $\hat{\boldsymbol{\alpha}}_{\boldsymbol{fs}} = \mathbf{0}$.

- $\Delta V = \{(1-\sigma)\upsilon_A + \sigma\beta_{SS}\omega_1\}\hat{\alpha}_{A1} > 0$ if β_{SS}
- $\Delta\hat{L}_A = (\varepsilon - \sigma)\,\beta_{RY}\Delta V/(\varepsilon + \eta) + (\sigma - 1)\hat{\alpha}_{A1}$
- $\Delta\hat{L}_B = (\varepsilon - \sigma)\,\beta_{RY}\Delta V/(\varepsilon + \eta)$

Case 4: Augmentation of the non-intensive factor in sector 1: $\hat{\boldsymbol{\alpha}}_{\boldsymbol{B1}}$>0, all other $\hat{\boldsymbol{\alpha}}_{\boldsymbol{fs}} = \mathbf{0}$.

- $\Delta V = \{-(1-\sigma)\upsilon_B + \sigma\beta_{SS}(1-\omega_1)\}\hat{\alpha}_{B1}$
- $\Delta\hat{L}_A = (\varepsilon - \sigma)\,\beta_{RY}\Delta V/(\varepsilon + \eta)$
- $\Delta\hat{L}_B = (\varepsilon - \sigma)\,\beta_{RY}\Delta V/(\varepsilon + \eta) + (\sigma - 1)\hat{\alpha}_{\mathrm{B1}}$

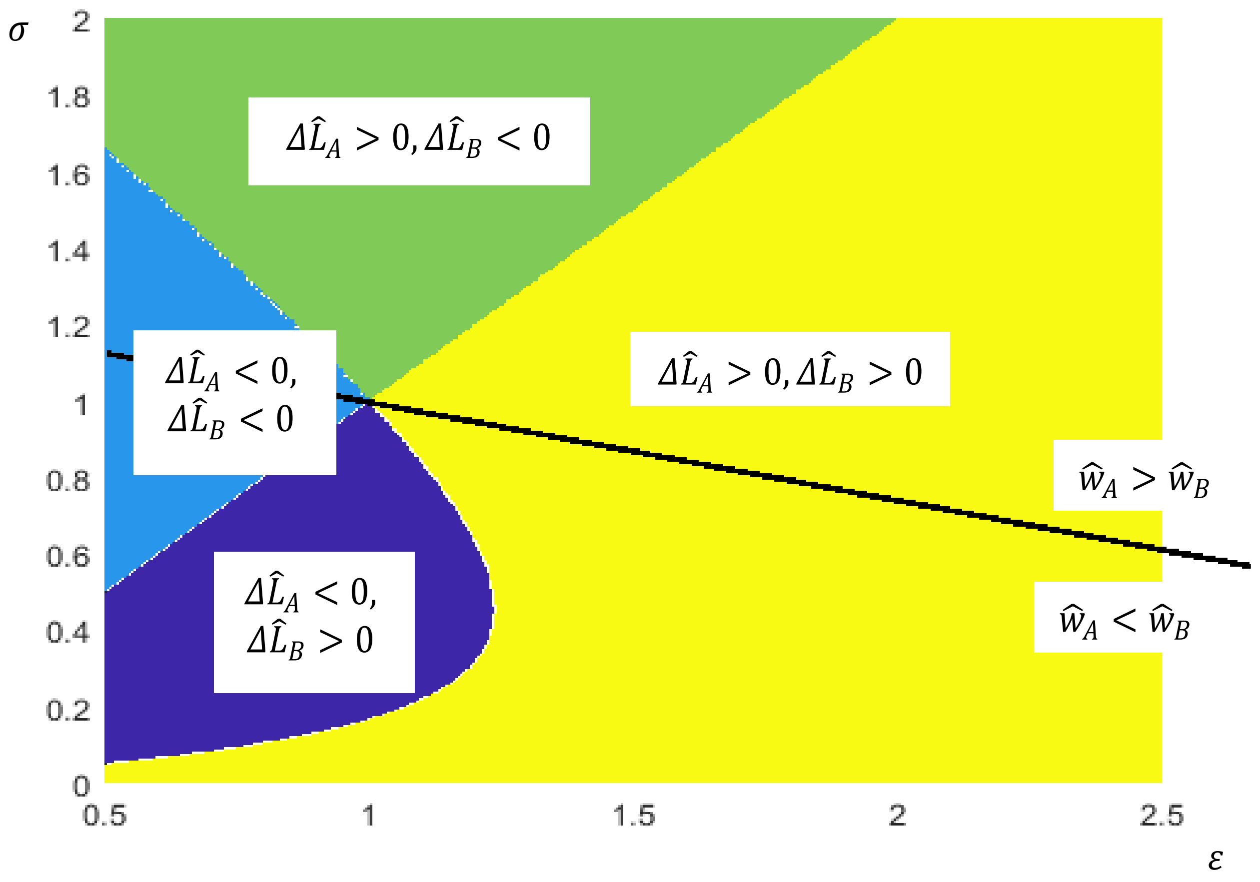
NOTE:

- ✓ Relative employment effects for factors A and B differ.
- ✓ The non-augmented factor is always determined by $(\varepsilon - \sigma)$ and $\beta_{RY}\Delta V$.
- ✓ ΔV may be positive or negative, as the cost-saving and the factor-saving impacts may draw in opposite directions (as in case 4).

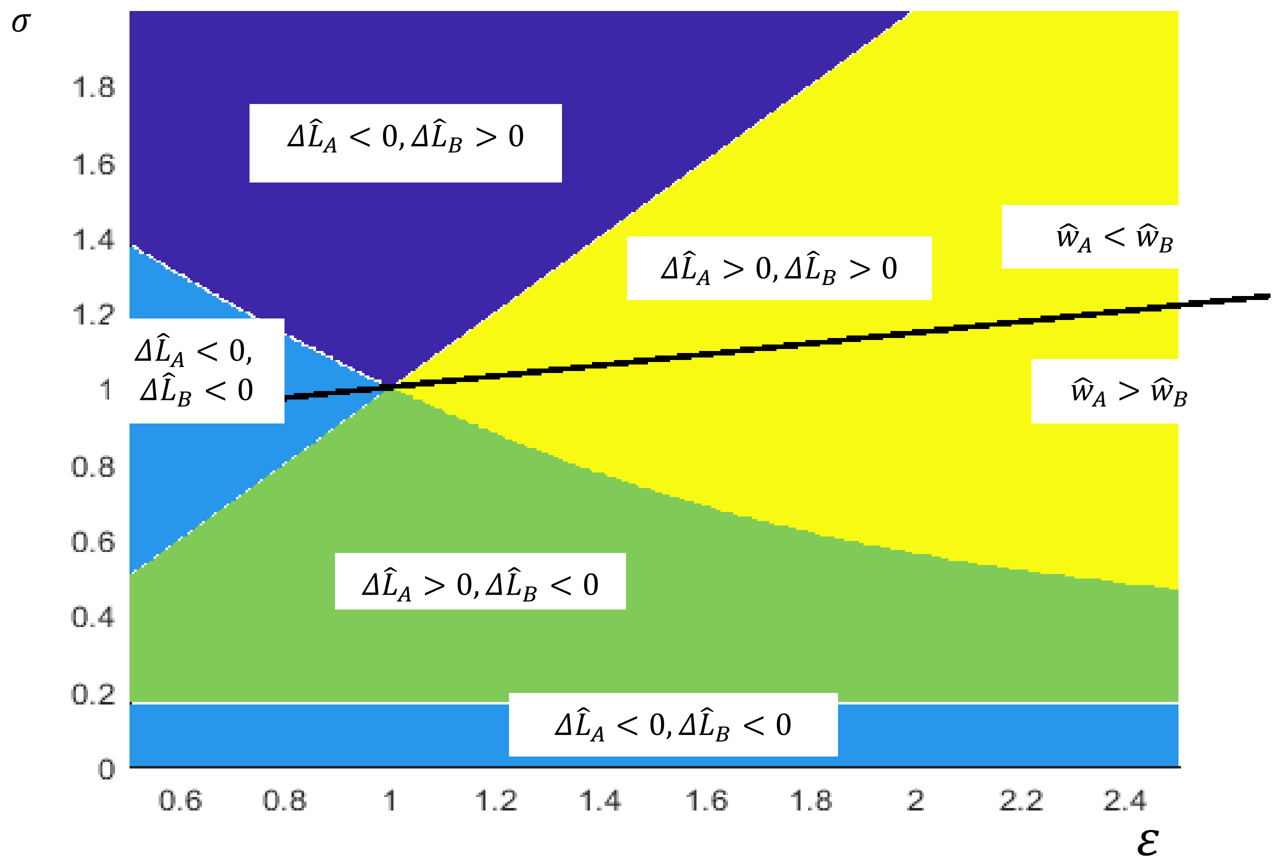
Figure 1 illustrates symmetric cases.

Sector-factor-specific technical progress - examples

Augmentation of factor A in A-intensive sector



Augmentation of factor B in A-intensive sector



Open economy issues: Country size, uniqueness of shock and non-traded goods

Openness and size mitigate the impact of domestic output changes on domestic prices

- We saw small-open economy extreme; in the paper we study the large, open economy cases.

Technical progress in one or all countries

- If technical progress takes place in (only) one country with good export opportunities, the elasticity of demand is high and positive wage and employment effects in the affected sector/factor are more likely.
- If technical progress takes place in all countries simultaneously, the effects are like in a closed (world) economy, with lower elasticity of demand.

How does allowing for a non-traded sector matter?

- Indicative answer: It will increase the relative factor supply elasticity (η), and thus dampen relative price effects and reinforce relative production and employment effects.

Some conclusions

- Labour and technology literature has looked at the nature of technology shocks, and the theory has studied limited general equilibrium mechanisms. We show that an important missing element is the interplay between the nature of the shock and the nature of the sector(s) in which it occurs.
- This implies that three elasticities matter, not just one or two.
- There is not a one-to-one correspondence between relative wage effects and relative employment effects, so we need to study both.