Labor Demand: The Role of Technology in the Evolution of the Skill Wage Premium

Econ 350
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Evolution of skill wage premium

- One of the most important regularities in the U.S. labor market over the last four decades is the rise in the relative wages paid to college-educated workers.
Role of demand

- Given the observed movements in the relative quantities, the price changes could not be generated by movements “along the production function”.
- Shifts in the demand for college-educated labor can reconcile the increase in the skill premium and increase in relative supply.
Skill premium: last century

- The skill premium fell precipitously in the first half of the century and rose again until the current period (e.g. Goldin and Katz, 1999). The pattern is “U-shaped”.

![Graph showing the skill premium over time]
Skill premium: other countries

- The rise in the skill premium is not a widespread phenomenon.

Table 1: Change in the skill premium during the last two decades

<table>
<thead>
<tr>
<th>Country</th>
<th>Observed change in the skill premium</th>
<th>Period</th>
<th>Definition of skill premium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>2.1%</td>
<td>1990-1999</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Austria</td>
<td>-9.9%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Brazil</td>
<td>5.6%</td>
<td>1996-2007</td>
<td>non-prod./prod. workers wage ratio</td>
</tr>
<tr>
<td>Canada</td>
<td>-1.2%</td>
<td>1990-2004</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Chile</td>
<td>-5.0%</td>
<td>1990-2000</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>China</td>
<td>40.2%</td>
<td>1992-2006</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Colombia</td>
<td>26.4%</td>
<td>1990-2006</td>
<td>college/high school wage ratio</td>
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<tr>
<td>Denmark</td>
<td>-2.3%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Finland</td>
<td>1.4%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>France</td>
<td>-16.8%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
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<td>Germany</td>
<td>14.4%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
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<tr>
<td>Greece</td>
<td>-2.4%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
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<tr>
<td>India</td>
<td>11.9%</td>
<td>1987-2004</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Italy</td>
<td>29.8%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Japan</td>
<td>-3.4%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Korea</td>
<td>-6.6%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
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<tr>
<td>Mexico</td>
<td>12.5%</td>
<td>1990-2001</td>
<td>non-prod./prod. workers wage ratio</td>
</tr>
<tr>
<td>Peru</td>
<td>23.9%</td>
<td>1994-2000</td>
<td>non-prod./prod. workers wage ratio</td>
</tr>
<tr>
<td>Portugal</td>
<td>12.3%</td>
<td>1992-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>Philippines</td>
<td>5.0%</td>
<td>1988-2006</td>
<td>college/high school wage ratio</td>
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<td>Spain</td>
<td>8.2%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
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<tr>
<td>Sweden</td>
<td>9.0%</td>
<td>1990-2002</td>
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<td>Thailand</td>
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<td>United Kingdom</td>
<td>2.0%</td>
<td>1990-2005</td>
<td>college/high school wage ratio</td>
</tr>
<tr>
<td>United States</td>
<td>3.1%</td>
<td>1990-2007</td>
<td>non-prod./prod. workers wage ratio</td>
</tr>
<tr>
<td>Uruguay</td>
<td>11.1%</td>
<td>1990-1999</td>
<td>college/high school wage ratio</td>
</tr>
</tbody>
</table>
Skill premium: still a puzzle

- The literature has often used supply-demand-institution (SDI) explanation for wage structure changes. The SDI has three parts:
  1. Supply and Demand Shocks
  2. Interactions of Market Forces and Institutions
  3. Institutional Changes

- Besides SDI, there is also evidence on compositional and selection effects on the supply and demand sides.
The literature still debates the reasons behind the rise in wage inequality.

On one hand, some researchers (e.g. Murphy and Katz, 1992, and Autor, Katz, and Kearney, 2008) use demand side arguments. In particular, they argue that skill-biased technological change (SBTC) and capital-skill complementarity (KSC) can explain the increase in wage premium.

On the other hand, some studies claim that institutional factors such as the erosion of labor unions and minimum wage (Lemieux, 2006) and the supply-side factors were likely to have played a relevant role in the dynamics.
Skill premium: still a puzzle

- It is essential to have a good understanding of the true effects as they have very different policy implications.
  - The SBTC and KSC hypothesis are more likely to be unalterable, since it is not clear what could policy-makers do to countervail the effects of technological change on rising inequality.
  - The institutions/compositional view see the recent rise in the U.S. earnings inequality as a short/medium-term phenomenon created by a couple of one-time events, or as a direct consequence of policies that can be reverted.
Skill premium: still a puzzle

- In the spirit of the supply-demand-institution explanation for wage structure changes, I will use neoclassic models (i.e. models where wages directly reflect marginal productivity) to explore the contribution of demand and technological factors for the increase in wage inequality across skill groups.

- In these models, firms:
  - Hire labor of different skill levels
  - Operate in a competitive, frictionless labor market

- As a result, wages are affected by technology in a very direct way. Changes in returns to education will be directly tied to changes in technology. Within these kinds of theories the shape of the production function of a firm/sector is crucial.
Roadmap

1. What do we know about aggregate production functions?
2. The SBTC and the KSC hypothesis
3. Going beyond aggregate technologies:
   - Evidence by industry
   - Evidence by occupations
4. The role of trade and offshoring
5. Making technology endogenous
1. What do we know about aggregate production functions?
What do we know about aggregate production functions?

- Level of aggregation
- Aggregation of inputs and aggregation of output
- Functional form assumptions and stability over time
  - CES, VES, GPF
- Incorporation of technological change:
  - Hicks neutrality, Labor- and capital-augmenting
  - Exogenous vs. Endogenous nature
  - Short-run vs. Long-run
1.1 Labor and capital aggregated into single index. Workhorse I: Cobb-Douglas

\[ Y_t = F(L_t, K_t) = A_t L_t^\alpha K_t^{1-\alpha} \]

where:
- Only two inputs: capital (K) and labor (L)
- Hicks factor neutral technical change (\(A_t\) is an efficiency shifter)
- Elasticity of substitution between inputs equals 1
Why was (is?) so extensively used?

- Allows for a BGP
- And one of the most prominent empirical stylized facts

**Figure 1. Labor Share in Total Value Added in the U.S. Corporate Sector from Piketty and Saez (2001)**

*Source:* National Accounts, National Income and Productive Accounts (NIPA) Table 1, 16.
Why was (is?) so extensively used?
Workhorse II: CES

- Pioneering work by Solow (1956, 1957) and Arrow et. al. (1961)

\[ Y_t = F(\Gamma^K_t K_t, \Gamma^L_t L_t) = C \left[ \pi(\Gamma^K_t K_t) \frac{\sigma-1}{\sigma} + (1 - \pi)(\Gamma^L_t L_t) \frac{\sigma-1}{\sigma} \right] \frac{\sigma}{\sigma-1} \]

where:

- \( \pi \in (0, 1) \) is a parameter that reflects the capital intensity in the economy, \( C \) is an efficiency parameter, \( \sigma \) is the elasticity of substitution between capital and labor, \( \Gamma^K_t \) and \( \Gamma^L_t \) captures the capital and labor-augmenting technical progress, respectively.
- Nested cases: \( \sigma = 1 \) is Cobb-Douglas; \( \sigma = 0 \) is the Leontieff and \( \sigma \to \infty \) is perfect substitutability.
Empirical research on workhorse I vs. workhorse II: i) data

- Time series Vs. Cross sectional/country Vs. Panel data
  - Lucas (1969) discusses several biases inherent to the use of cross-sectional data in the estimation of the elasticity and suggests the use of time series data as an alternative.
  - Durlauf et al. (2001) argues that the assumption of a single linear model representing all countries is inappropriate: models with parameters that are country-invariant are implausible in light of the vast heterogeneity that exists among countries.
i) data

- Empirical testing requires data on:
  - Flow and price of labor services (see Jorgenson and Ho (2000) for quality-adjusted measures of labor services and Krueger (1999) or Goldin (2002) for discussion on adding proprietor’s income to the overall compensation of employees);
  - Flow and rental price of capital services (correct measurement of the user cost and capital income are very controversial, especially because capital is a quasi-fixed input in production). See for example, Basu (1996) for discussion about using capital services as a proportion of the capital stock, and Gordon (1990) for an alternative deflator for equipment that accounts for increases in quality.
  - Aggregate output and its associated price.
ii) Modeling choices: Labor and capital augmenting technological progress and the elasticity of substitution

- Diamond, McFadden and Rodriguez (1978), formally proved the impossibility of identifying the roles of factor substitution and nature of technological changes. The literature has generally circumvented this impossibility by imposing some type of structure on the form of technological change. (most papers assume that the elasticity grows exponentially at a constant rate, e.g. Antràs (2004));
ii) Modeling choices: Labor and capital augmenting technological progress and the elasticity of substitution

- Several papers cite Berndt’s (1976) paper as evidence in favor of the Cobb-Douglas functional form. In this paper the technological change is Hicks neutral and the data shows capital-labor ratio growing through time. The finding of a unit elasticity of substitution should not be surprising since the only aggregate production function consistent with constant factor shares is one featuring a unit elasticity of substitution between capital and labor;

- Studies that allow for biased technological change are only consistent with constant shares of inputs (and BGP) when there is net labor-augmenting technological change (Barro and Sala-i-Martin, 1995)
iii) Modeling choices: Equations or system of equations

- Single equations estimates
- System of equations (error terms are likely to be correlated)
  - In a supply-side system approach, the first-order conditions of a profit maximizing firm are used in a system, containing cross-equation parameter constraints, that aid in the identification of structural parameters such as the elasticity of substitution or the technical progress parameters.
Econometric techniques

- OLS or NLLS
  - Durbin-Watson to check for serial correlation of the residuals
  - Dickey-Fuller test for the existence of unit roots,
  - Johnsen-Juselius cointegration tests

- FGLS
  - Ljung-box tests;
  - Two-steps (Prais-Winsten procedure)

- 2SLS, GIV and GMM (instruments vary across applications); (e.g. wages in the government sector, capital stock owned by the government, lagged variables)

- Supply-system approach
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Assumption</th>
<th>$\hat{\sigma}$</th>
<th>$\hat{\gamma}_N$</th>
<th>$\hat{\gamma}_K$</th>
<th>$\hat{\gamma}_N - \hat{\gamma}_K$</th>
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<tr>
<td>Arrow et al. (1961)$^a$</td>
<td>1909-1949</td>
<td>Hicks neutral</td>
<td>0.57</td>
<td>1.8</td>
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<td>Kendrick and Sato (1963)$^b$</td>
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<td>Brown and De Cani (1963)$^a$</td>
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<td>Factor augmenting</td>
<td>0.35</td>
<td>Labor saving</td>
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<td></td>
<td>1919-1937</td>
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<td>0.62</td>
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<td></td>
<td>1938-1958</td>
<td></td>
<td>0.11</td>
<td>Labor saving</td>
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<td>1939-1958</td>
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<td>David and van de Klundert (1965)$^a$</td>
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<td>Bodkin and Klein (1967)$^c$</td>
<td>1909-1949</td>
<td>Hicks neutral</td>
<td>0.5-0.7</td>
<td>1.4—1.5</td>
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<td>Wilkinson (1968)$^d$</td>
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<td>Labor saving</td>
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<td>Sato (1970)$^a$</td>
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<td>Factor augmenting</td>
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<td>2.0</td>
<td>1.0</td>
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<td>Panik (1976)$^a$</td>
<td>1929-1966</td>
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<td>0.76</td>
<td>Labor saving</td>
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<td>Berndt (1976)$^e$</td>
<td>1929-1968</td>
<td>Hicks neutral</td>
<td>0.96—1.25</td>
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<td>Kalt (1978)$^e$</td>
<td>1929-1967</td>
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<td>0.76</td>
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<td>Antras (2004)$^e$</td>
<td>1948-1998</td>
<td>Hicks neutral</td>
<td>0.94—1.02</td>
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<td>Klump et al. (2007a)$^f$</td>
<td>1953-1998</td>
<td>Factor augmenting</td>
<td>0.51</td>
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<td>1.7</td>
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</table>

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<table>
<thead>
<tr>
<th>Study</th>
<th>Countries</th>
<th>Sample (Frequency)</th>
<th>Assumption</th>
<th>( \hat{\sigma} )</th>
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<tr>
<td>Lewis and Kirby (1988)</td>
<td>Australia 1967-1987 (Weekly)</td>
<td>Hicks-Neutral</td>
<td>0.78</td>
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<tr>
<td>Bolt and van Els (2000)</td>
<td>Austria, Belgium, Germany, Denmark, Spain, Finland, France, Italy, Netherlands, US, Sweden, UK, Japan 1971-1996 (Quarterly)</td>
<td>Hicks-Neutral</td>
<td>0.24, 0.78, 0.53, 0.61, 1.0, 0.34, 0.73, 0.52, 0.27, 0.82, 0.68, 0.6, 0.3</td>
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<td>Duffy and Papageorgiou (2000)</td>
<td>82 developed and developing countries 1960-1987 (Annual)</td>
<td>Hicks-Neutral</td>
<td>1.4</td>
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<td>Ripatti and Vilmunen (2001)</td>
<td>Finland 1975-1999 (Quarterly)</td>
<td>Factor Augmenting</td>
<td>0.6</td>
<td></td>
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<tr>
<td></td>
<td>Germany 1983-1999 (Quarterly)</td>
<td>Hicks Neutral</td>
<td>0.7-1.2</td>
<td></td>
</tr>
</tbody>
</table>
Recent contributions

- Klump, R., P. McAdam and A. Willman (2007, REStat); León-Ledesma, M., P. McAdam and A. Willman (2010, AER);

- They claim to be able to estimate the elasticity of substitution between factors and the nature of the technological progress, thus overcoming the impossibility theorem of Diamond et al. (1976). A innovative supply-side system approach is used and Monte Carlo sampling techniques are applied to test it.

- The estimation was conducted for the US economy from 1953 to 1998. The estimated elasticity of substitution is significantly below one (between 0.5 and 0.7) and the growth rates of technical progress show an asymmetrical pattern where the growth of labor-augmenting technical progress is almost exponential, while that of capital is hyperbolic or logarithmic.
Monte Carlo Sampling in León-Ledesma et al., 2010

• Different approaches are ranked in terms of their ability to replicate a predetermined data generation process (DGP). A wide range of techniques (single equation, systems linear, non-linear, linearized) are analyzed.

• Main findings are:
  • Superiority of the system approach (i.e., jointly modeling the production function and first-order conditions) in terms of robustly capturing production and technical parameters;
  • Single equation approaches are largely unsuitable for jointly uncovering technical characteristics. This applies also to a generalized form of the Kmenta approximation (for which some weak technical identification results are derived);
  • Direct estimation of the nonlinear CES does not alleviate identification problems (especially for high elasticity cases).
Method proposed in Klump et al., 2007

- Normalization of a CES production with biased technological change:

\[ Y_t = Y_0 \left[ \pi_0 \left( \frac{\Gamma^K_t K_t}{K_0} \right)^{\frac{\sigma-1}{\sigma}} + (1 - \pi_0) \left( \frac{\Gamma^L_t L_t}{L_0} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \]

- where \( \Gamma^K_0 = \Gamma^L_0 = 1 \) and \( \pi_0 = \frac{r_0 K_0}{r_0 K_0 + w_0 L_0} \).

- The need for normalization was pointed out by Klump and de La Grandville (2000). The intuition is that the CES function is homothetic and to be able to distinguish models according to their different elasticities of substitution it is necessary to fix benchmark values for the level of production, factor inputs, and for the marginal rate of substitution (or equivalently for per-capita production, capital deepening, and factor income shares).
The Supply-Side System Approach

\[ \log (r) = \log \left( \frac{\bar{Y}}{\bar{K}} \right) + \frac{1}{\sigma} \log \left( \frac{\gamma/\bar{Y}}{K/\bar{K}} \right) + \frac{\sigma - 1}{\sigma} (\log(\xi) + \gamma_K(t - \bar{t})) \]

\[ \log (w) = \log \left( \left(1 - \bar{\pi}\right) \frac{\bar{Y}}{\bar{K}} \right) + \frac{1}{\sigma} \log \left( \frac{\gamma/\bar{Y}}{N/\bar{N}} \right) + \frac{\sigma - 1}{\sigma} (\log(\xi) + \gamma_N(t - \bar{t})) \]

\[ \log \left( \frac{\gamma/\bar{Y}}{\bar{Y}} \right) = \log(\xi) + \frac{\sigma}{\sigma - 1} \log \left( \frac{\pi}{\sigma} \left( e^{\gamma_K(t - \bar{t})} \frac{K}{\bar{K}} \right)^{\frac{\sigma - 1}{\sigma}} + (1 - \bar{\pi}) \left( e^{\gamma_N(t - \bar{t})} \frac{N}{\bar{N}} \right)^{\frac{\sigma - 1}{\sigma}} \right) \]

- To test for different types of factor augmenting technology the Box-Cox (1964) was used.
1.2 Production functions with labor and capital disaggregated

- Heterogeneity and aggregation problems have been a concern in economic theory for a long time. However, the need for simple analysis and the existence of implementation problems limits the use of heterogeneous components in factor inputs, such as: high and low-skill types of labor and different strata of capital (equipments, software, buildings and infrastructure).

- In the inequality literature, aggregation is particularly problematic. Some important aspects, such as the effect of the changes in the return to different labor input skills, accumulation of capital and technical progress on income distribution are lost with the aggregation.
Disaggregation of labor and capital: why?

- Equipment capital displays a positive trend, while structures capital has a negative trend over the sample. The increase in the ratio between equipment and structures capital reflects the downward trend in their relative user prices.
- These opposite trends largely compensate each other, thus their relative factor income shares remain relatively stable only marginally favoring equipment capital.
One of the most salient observations concerning the U.S. labor market over the past thirty years is the simultaneous rise in the wage paid to college-educated workers and the increase in the supply of such workers;

Both relative input and wage developments favors skilled labor, i.e. both of them have an upward trend implying an even steeper trend in the income of skilled labor to that of unskilled labor.
The seminal contribution of Sato (1967) proposed a nested two-level CES

\[
Y_t = A_t \left\{ \beta \left[ \alpha \frac{X_{1t}^{\sigma_x-1}}{\sigma_x} + (1 - \alpha)X_2^{\sigma_x-1} \right] \frac{\sigma_x^{\sigma_x-1}}{\sigma_x} \frac{\sigma - 1}{\sigma} + (1 - \beta) \left[ \gamma \frac{Z_{1t}^{\sigma_z-1}}{\sigma_z} + (1 - \gamma)Z_2^{\sigma_z-1} \right] \frac{\sigma_z^{\sigma_z-1}}{\sigma_z} \frac{\sigma - 1}{\sigma} \right\}
\]

where \( A_t \) is a positive (factor neutral) efficiency parameter, \( X_i \) are \( Z_i \) are different aggregate factor inputs and \( i = 1, 2 \) are different factor categories.
Nested CES

- Nested CES specifications have an important limitation: they are not invariant to the nesting structure. Different nesting structures imply different assumptions about the separability between inputs. For example, a two-level nested CES with three inputs takes the form

\[ Y = F \left( g(X_1, X_2), Z \right) \]

where \( Y \) is the gross output; \( X_1, X_2 \) and \( Z \) are inputs; and \( X = g(X_1, X_2) \) represents the joint contribution of \( X_1 \) and \( X_2 \) to production. A special feature of the nested CES function is that the elasticity of substitution between the first-level inputs, \( X_1 \) and \( X_2 \), can be different from the elasticity of substitution between the second-level inputs, \( X \) and \( Z \).
Examples

- Stokey (1996)

\[ Y = A \left( \alpha K \frac{\sigma_{x-1}}{\sigma_x} + (1 - \alpha) L_N \frac{\sigma_{x-1}}{\sigma_x} \right)^\frac{\sigma}{\sigma-1} \theta \left( \tilde{L}_S \right)^{1-\theta} \]

where \( L_S \) is skilled-labor services, \( L_N \) is unskilled-labor services, \( \tilde{L}_S = L_S + qL_N \) represents mental effort, \( q < 1 \) is the relative efficiency of unskilled labor.


\[ Y = A \left\{ \beta \left[ \alpha K \frac{\sigma_{x-1}}{\sigma_x} + (1 - \alpha) L_S \frac{\sigma_{x-1}}{\sigma_x} \right]^\frac{\sigma}{\sigma-1} \frac{\sigma-1}{\sigma} + (1 - \beta)L_N \frac{\sigma-1}{\sigma} \right\} \]

where \( L_S \) is skilled-labor services, \( L_N \) is unskilled-labor services, \( K \) is the stock of capital.
Examples

- Krusell, Ohanian, Rios-Rull and Violante (2000)

\[
Y = AK_s^\alpha \left\{ \beta \left[ \alpha K_e^{\frac{\sigma - 1}{\sigma}} + (1 - \alpha)L_s^{\frac{\sigma - 1}{\sigma}} \right]^{\frac{\sigma}{\sigma - 1}} + (1 - \beta)L_N^{\frac{\sigma - 1}{\sigma}} \right\}^{\frac{\sigma}{\sigma - 1}}
\]

where \(K_s\) is the stock of capital structures, \(K_e\) is the stock of capital equipment, \(L_s\) is skilled-labor services, \(L_N\) is unskilled-labor services
Limitations

- Do not incorporate factor augmenting progress; (missing variable problem)
- The impact of factor accumulation depends crucially on the relative values of the elasticity of substitution determined by $\sigma, \sigma_X$ and $\sigma_Z$ (problems with strong separability).
- The choice of the specific nested two-level CES determines the results and complicates comparisons across models. None of the papers mentioned above tested the specification.
  - Duffy et al. (2004) compares some of those using a 25-periods panel of 73 countries: data fits better when the elasticities of substitution between $K$ and $L_N$ and between $L_N$ and $L_S$ are the same.
2. The SBTC and the KSC hypothesis
Moving beyond total factor productivity

- The standard measure of aggregate technological change, total factor productivity (TFP), does not distinguish between the different ways in which technology grows. We need to move beyond and incorporate:
  1. Technology may have different effects on the productivity of different input factors (FSP)
  2. Technology growth may differ across sectors (SSP)

- The recent experience of developed countries seems to suggest that in the past 30 years technological change has originated in particular sectors of the economy and has favored particular inputs of production.
Moving beyond total factor productivity

- For example, the advent of microelectronics (i.e., microchips and semiconductors) induced a sequence of innovations in information and communication technologies with two features:
  
  1. SSP growth substantially increased the productivity of the sector that produces new capital equipment, making the use of capital in production relatively less expensive.
  2. FSP growth favored skilled and educated labor disproportionately.

- From this example, we have that the SSP motivates the KSC hypothesis (as formalized by Krusell, Oharian, Rius-Rull and Violante, 2000), while the FSP motivates the SBTC. There are concerns regarding the persistence of the KSC phenomenon. Goldin and Katz (1998) suggests that it may only be a transitory phenomena. As countries progress through various stages of development, skilled labor may change from being more substitutable with capital and unskilled labor to being highly complementary to these two inputs.
SBTC and KSC hypothesis: literature

- **KSC:**
  - Grilliches (1969) showed that – for US manufacturing – capital and skilled labor were more complementary than capital and unskilled labor. This spawned a considerable literature examining the so-called “capital-skill complementarity” hypothesis.

- **SBTC:**
  - Katz and Murphy (1992) show that the skill premium can be attributable to technical change that was biased in favor of skilled workers. Given that skilled and unskilled workers are gross substitutes, an increase in skilled labor efficiency led to an increase in the relative wages (and factor shares) of skilled workers.
The SBTC hypothesis

The canonical model is a framework that operationalizes supply and demand for skills

- A formalization of Tinbergen’s “Education Race” analogy.
- Two distinct skill groups that perform two different and imperfectly substitutable tasks (The only necessary condition is that skilled and unskilled work are gross substitutes such that the demand for labor shifts up).
- Builds in a CES production function where capital is separable from labor (or the degree of substitutability between different types of labor and capital is the same).
- Technology is factor-augmenting.
Canonical SBTC Model

• Basic Assumptions

1. Two skills, high and low: \( H, L \). Typically college v. high school
2. No distinction between skills and “tasks” – Skill is direct input into production
3. \( H \) and \( L \) are imperfect productive substitutes: \( \sigma > 0 \)
4. Wages are set on the demand curve

• Canonical representation

\[
Y = \left[ \left( A_L L \right)^{\frac{\sigma-1}{\sigma}} + \left( A_H H \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}
\]

where \( A_L \) and \( A_H \) are factor-augmenting technological terms.
Canonical SBTC Model

- Elasticity of substitution plays key role
  - $\sigma > 1$: $H$ and $L$ are gross substitutes. Rise in $A_H/A_L$ is SBTC
  - $\sigma < 1$: $H$ and $L$ are gross complements. Fall in $A_H/A_L$ is SBTC

\[
W_L = \frac{\partial Y}{\partial L} = A_L^{\sigma-1} \left[ A_L^{\sigma-1} + A_H^{\sigma-1} \left( \frac{H}{L} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{1}{\sigma-1}}
\]

\[
W_H = \frac{\partial Y}{\partial H} = A_H^{\sigma-1} \left[ A_H^{\sigma-1} \left( \frac{H}{L} \right)^{\frac{\sigma-1}{\sigma}} + A_H^{\sigma-1} \right]^{\frac{1}{\sigma-1}}
\]
Canonical SBTC Model

- Skill premium
  \[
  \ln \left( \frac{W_H}{W_L} \right) = \frac{\sigma - 1}{\sigma} \ln \left( \frac{A_H}{A_L} \right) - \frac{1}{\sigma} \ln \left( \frac{H}{L} \right)
  \]

- Supply and demand visible
  - \( \ln \left( \frac{H}{L} \right) \) represents position of “supply curve”
  - \( \frac{\sigma - 1}{\sigma} \ln \left( \frac{A_H}{A_L} \right) \) represents position of “demand curve”
  - Impact of supply on wage inequality
    \[
    \frac{\partial \ln \left( \frac{W_H}{W_L} \right)}{\partial \ln \left( \frac{H}{L} \right)} = -\frac{1}{\sigma}
    \]
  - Impact of factor technological change on wage inequality
    \[
    \frac{\partial \ln \left( \frac{W_H}{W_L} \right)}{\partial \ln \left( \frac{A_H}{A_L} \right)} = \frac{\sigma - 1}{\sigma} > 0 \text{ iff } \sigma > 1
    \]

Consensus is that \( \sigma \in (1.4, 2.5) \), so technology that rises relative output of \( H \) also raises its relative wage.
Canonical SBTC Model

Some key testable predictions

1. Rise in supply of $H/L$ reduces skilled wage differential
   - $\partial(w_H/w_L)/\partial(H/L) = -1/\sigma < 0$

2. Rise in supply of $H/L$ also raises real wage of $L$: $\partial W_L/\partial(H/L) > 0$
   - This follows from imperfect substitutability between $H$ and $L$ and complementarity

3. Factor augmenting technological $\Delta$ always raises wages of $L$ workers: $\partial W_L/\partial A_L > 0$ and $\partial W_L/\partial A_H > 0$
   - This also follows from imperfect substitutability

4. Predictions of this model always apply to both skills
   - A bit tautological since there are only two skills/wages
   - But assume a continuum of efficiencies in each skill group: still true
   - Loosely: Wage inequality is either rising or falling in this model not both
Canonical SBTC Model

- The two-factor model estimated by Katz and Murphy (1992):
  - Used data from 1963 through 1987, fit by OLS

\[
\ln \left( \frac{W_H}{W_L} \right) = \frac{\sigma - 1}{\sigma} \gamma_0 + \frac{\sigma - 1}{\sigma} \gamma_1 t - \gamma_2 \ln \left( \frac{H_t}{L_t} \right)
\]

- Replicating their approach, we get

\[
\ln \left( \frac{W_H}{W_L} \right) = 0.027 \times t - 0.612 \times \ln \left( \frac{H_t}{L_t} \right)
\]

- This estimate implies
  - Log relative demand for College/Non-College rising at 2.7 log points annually
  - Elasticity of substitution \( \hat{\sigma} = \frac{1}{\hat{\gamma}_2} \approx 1.6 \)

- You can see how well this works in the following figures
- Over predicts wage growth in the 2000s
Canonical SBTC Model
Canonical SBTC Model

2. Carneiro and Lee (2009): Fit to data for U.S. regions
   - Fit to data for three countries: U.S., U.K., Canada
   - Allow for imperfect substitutability among age cohorts
   - Explain cross-country variation in timing of rise of college premium and within-country variation in magnitude of rise in premium by age groups within countries.
   - See also Fitzenberger and Kohn (2006) for German application.
Canonical SBTC Model

- Within group inequality is invariant to skill prices.
  \[
  \frac{W_i}{W_{i'}} = \frac{w_L l_i}{w_L l_{i'}} = \frac{l_i}{l_{i'}} \quad \text{for } i, i' \in \mathcal{L}
  \]

- There can be within group wage inequality, but it will be independent of the skill premium.
Canonical SBTC Model

- It is possible to make within group inequality responsive to the wage premium.
- Assume that the two observable groups are college and non-college.
- Fraction of $\phi_c$ college graduates are high skill.
- Fraction of $\phi_n < \phi_c$ non-college graduates are high skill.
- Skill premium is $\omega = \frac{w_H}{w_L}$
- College wages, $w_C$, non-college, $w_N$.

$$\omega_C = \frac{w_C}{w_N} = \frac{\phi_C w_H + (1 - \phi_C) w_L}{\phi_N w_H + (1 - \phi_N) w_L} = \frac{\phi_C \omega + (1 - \phi_C)}{\phi_N \omega + (1 - \phi_N)}$$

- Like Gorman-Lancaster model
Canonical SBTC Model

• Because $\phi_n < \phi_c$ in $\omega$, when the true price of skill increases, the observed college premium will also arise.

• Trivially explains wage inequality within groups as a function of skill premium.
Canonical SBTC Model: limitations

But model largely silent on some central empirical facts of last three decades:

1. $\sigma$ combines substitution in production and consumption across consumers, across industries, etc.
2. Falling real wages of low-skill workers (at least in U.S.)
3. Non-monotone shifts in inequality, despite rising ‘return to skill’
4. Widespread ‘polarization’ of employment across advanced economies
5. Directly skill-replacing (not augmenting) technologies
• College premium rose by 12 points between 1992 and 2008. Model predicts a rise of 25 log points!
• Model implies demand decelerated after 1992 or elasticity $\sigma$ rose
Canonical SBTC Model: limitations
Canonical SBTC Model: limitations

Predicted Log Hourly Wages by Years of Education: Males

Years of Education

Predicted Log Hourly Wages

-4
-2
0
2
4
6
8
1
7 8 9 10 11 12 13 14 15 16 17 18

1973
1989
2009
Canonical SBTC Model: limitations

Changes in Male Log Hourly Wages by Percentile Relative to the Median

- Relative log earnings change
- Hourly Earnings Quantile

- 1974-1988
- 1988-2008
Canonical SBTC Model: limitations

Changes in Female Log Hourly Wages by Percentile Relative to the Median

Hourly Earnings Quantile

Relative log earnings change

1974-1988
1988-2008
The KSC hypothesis

- Since Griliches (1969) economists have been quite receptive to the idea that the advent of a new technology (especially an information processing technology) would raise relative demand for skilled workers.
- If this hypothesis is correct, capital deepening that is the process of capital accumulation will tend to increase the relative demand for skilled labor.
- The paper that takes this idea most seriously/literally is Krussell, Ohanian, Rios-Rull and Violante (2000, Econometrica) (KORV)
The KSC hypothesis

• KORV build on:
  • Relative price of capital equipment has been falling steadily in the postwar period. Moreover, this rate of decline of equipment prices may have accelerated sometime during the mid to late 1970s. (Gordon, 1990)
  • The assumption of capital-skill complementarity.

These two together can potentially give rise to an increase in the relative demand for skilled labor.
The KSC hypothesis: limitations

First, the measure of the capital-skill complementarity effect on relative wages evolves similarly to a linear time trend. The KORV time series on capital equipment prices is not the variable providing the explanatory power in their model; it is primarily the supply measure that is affecting the skill premium as in the SBTC canonical model. Acemoglu (2002) estimates the Katz-Murphy regression augmented with the KORV series for relative capital prices and a simple linear time trend:

- Shows that the KORV measure performs worse than a linear time trend. In fact, it is never significant when a time trend is included.
The KSC hypothesis: limitations

Second, measuring the real (or even relative) price of capital is notoriously difficult. Because of issues of quality improvement and inflation, one needs to be quite skeptical about making too much of a potential change in the rate of change (i.e., the second derivative) of a price series.

Finally, one would generally expect a decline in the price of capital to have given rise to greater productivity growth. However, income stagnated in exactly the period when relative equipment prices were ostensibly declining. On the contrary, a skill-biased technological shift does not have to raise living standards by a great deal to substantially affect relative earnings.
State of the Art

• As you will see, aggregate production functions lie at the heart of macroeconomic analysis and disaggregation of skill and unskilled labor is essential to study the evolution of skill wage premium. Yet, there is clearly a lack of consensus on the nature of the technology. The empirical contributions concerning the role of KSC relative to SBTC are far from satisfactory because they do not allow for both possibilities.

  • Katz and Murphy (1992) allows for SBTC but imposes that the elasticity of substitution between capital and skill labor is equal to the elasticity of substitution between capital and unskilled labor.
  • Krusell et al. (2000) allows for an elasticity of substitution between capital and skill labor different of the elasticity of substitution between capital and unskilled labor, but imposes factor neutral technological change.
State of the Art

• To empirically gauge the relative importance of the KSC and the SBTC, the researcher needs to make important decisions regarding the nature of the data, the functional form specifications and relevant indicators to test the two hypothesis.

• To address the importance of the KSC hypothesis and SBTC, the main outcomes of interest of the different models will be

\[
\frac{\partial (\ln W_{skilled} - \ln W_{unskilled})}{\partial \ln K} \quad \text{and} \quad \frac{\partial (\ln W_{skilled} - \ln W_{unskilled})}{\partial (\ln A_{skilled} - \ln A_{unskilled})}
\]
State of the Art

• “Necessary” assumptions and challenges:
  • Elasticity of substitution for models with more than two inputs is not a clear concept. The literature provides two popular definitions: the Allen-Uzawa elasticity of substitution (Allen 1938 and Uzawa 1962) and the Morishima elasticity of substitution (Morishima 1967).
  • Needs to rely on the CRS assumption.
  • Need a framework that jointly identifies the nature of technical progress and the nature of complementarity/substitutability between inputs. A nested-CES functional form, allowing for biased technological change may be the best option.
  • Since Diamond, McFadden and Rodriguez (1978), we know that we need to assume a functional for the nature of technological change: exponential, box-cox, etc.
3. Going beyond aggregate technologies: evidence by industries and occupations
Beyond the SBTC and KSC black-boxes

- Bartel and Lichtenberg (1987) have shown that as new technology is adopted, the demand for highly educated workers increases relative to the demand for less educated workers.
  - Two potential explanations: (1) the more educated workers’ advantage derives from problem-solving ability and receptiveness to change in the working environment; (ii) computers and other advanced machinery have replaced less skilled workers in the performance of certain tasks.

- Krueger (1993) demonstrates that workers who used computers earned 10 to 15 percent more than observationally equivalent workers who did not.

- Berman, Bound, and Griliches (1994) find that the increase in demand for skilled workers relative to unskilled workers within manufacturing industries during the 1980s could be linked to investment in computers and in research and development.
Going beyond aggregate technologies: occupations

Smoothed Changes in Employment by Occupational Skill Percentile 1979-2007

100 x Change in Employment Share

Skill Percentile (Ranked by Occupational Mean Wage)

Going beyond aggregate technologies: occupations

Percent Change in Employment by Occupation, 1979-2009

-2 0 2 4 6

Percent Change

Managers Professionals Technicians Sales Official-Admin Production Operable/Laborers Protective Service Food/Cleaning Service Personal Care

Going beyond aggregate technologies: occupations
Going beyond aggregate technologies: occupations
Going beyond aggregate technologies: industries

There is substantial heterogeneity across sectors:

- Jorgenson, Gollop and Fraumeni (1987) and Jorgenson and Stiroh (2000) applied the Solow growth accounting procedure and obtain measures of sector-specific technical change. They documented the substantial differences in output and TFP growth rates across U.S. industries over the period 1958–1996. In particular, they point out that TFP growth rates in high-tech industries producing equipment investment are about three to four times as high as the aggregate TFP growth.

- Also based on industry data, Oliner and Sichel (2000) and Jorgenson (2001) attribute a substantial part of the increase of aggregate TFP growth over the second half of the 1990s to one industry: semiconductors.

- Young (2010) estimates the elasticity of substitution between capital and labor for 35 industries and finds substantial variability
The aggregation problem

Is the concept of aggregate production function meaningful?

- The conceptual problems behind the existence of an aggregate production function, include both the **heterogeneity of inputs/outputs** and the **aggregation across firms/industries**.

- The main estimation limitation comes from the identity problem that arises from using value data.

- **Felipe and Fisher (2003)** who claim that the aggregate or macro production function is a “fictitious entity” since aggregation requires extremely restrictive conditions that actual economies do not satisfy.

- At the same time as argued by **Solow (1987)**: “The current state of play with respect to the estimation and use of aggregate production functions is best described as Determined Ambivalence. We all do it and we all do it with a bad conscience...One or more aggregate production functions is an essential part of every complete macro-econometric model...It seems inevitable...There seems no practical alternative... Yet, nobody thinks there is such a thing as a ‘true’ aggregate production function. Using an estimate of a relation that does not exist is bound to make one uncomfortable”.

Econ 350, Sara Moreira
4. The role of trade and offshoring
The trade argument

• Trade
  • There was substantial growth in world trade flows in the United States, specially during the 1970s (not the 1980s).
  • Trade between countries with different factor endowments will change relative prices and will therefore raise or lower inequality among owners of those factors (depending on whether your country has more of the relatively scarce or abundant factor after trade opening)
  • This hypothesis has numerous testable implications.

• Outsourcing
  • This is subtly different from trade. Rather than opening factor markets to trade, you simply purchase certain factor-intensive inputs from overseas and turn them into final products in your own country.
  • Observationally, this can look a lot like SBTC, but not always.
The trade argument

Main channels explored in the literature:

1. Outsourcing: developed countries outsource intermediate production into countries with less expensive labor.
   - Acemoglu, Gancia and Zilibotti (2012)

2. Complementarity of capital with skilled labor and growth in capital flows

3. SBTC in both developing and developed countries.
   - Attanasio, Goldberg, and Pavcnikís (2004) findings show that in Mexico, even low-skill intensity industries have been skill biased in technological advancements.
   - Burstein and Vogel (2012)
The trade argument: The Stolper-Samuelson Theorem

The Stolper-Samuelson Theorem

- Predicts the relationship between goods prices and factor prices.
- Consider a world in which there are two factors of production, skilled labor and unskilled labor, and two goods produced competitively under constant returns to scale, a skilled labor–intensive good X and an unskilled labor–intensive good Y. Assume provisionally that an economy produces both goods. Then there is a one-to-one relationship between the relative prices $P$ of the two goods and the relative wages $w$ of the two types of labor.
- Predicts a decline in the skill premium in unskilled labor abundant countries through an inter-industry reallocation of labor.
- The factor price equalization theorem in its most stringent form predicts that if goods sell for the same price regardless of where they are produced, then workers who produce them will earn equal wages.
The trade argument: data

- Developing country U.S. imports have roughly doubled as a share of the U.S. economy since 1989.
- Recently, there is a marked increase in the sophistication of the goods the United States imports from developing countries. In particular, a sharp increase in imports of computers and electronic products compared with traditional unskilled labor-intensive goods such as apparel.
The trade argument: data

- Developing countries have substantially lower average wages, relative to wages in developed countries. In fact, countries where growth in trade is occurring today have even lower average wages than those where the growth was occurring in the early 1990s.

<table>
<thead>
<tr>
<th>Year</th>
<th>Top ten trading partners (largest first)</th>
<th>Average hourly compensation (percent of U.S. average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>Canada, Japan, Germany, United Kingdom, Mexico, France, Italy, Brazil, the Netherlands, Belgium</td>
<td>76</td>
</tr>
<tr>
<td>1990</td>
<td>Canada, Japan, Mexico, Germany, United Kingdom, Taiwan, South Korea, France, Italy, China</td>
<td>81b</td>
</tr>
<tr>
<td>2005</td>
<td>Canada, Mexico, China, Japan, Germany, United Kingdom, South Korea, Taiwan, France, Malaysia</td>
<td>65c</td>
</tr>
</tbody>
</table>


a. Averages are weighted by the countries’ shares in total U.S. trade.

b. China’s hourly compensation is assumed to be 1 percent of the U.S. level.

c. Malaysia’s hourly compensation is estimated from United Nations data.
The trade argument: data

- The data shows that non-college workers are more likely to be displaced by trade:

<table>
<thead>
<tr>
<th>Period</th>
<th>College graduates b</th>
<th>Non-college graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979–89</td>
<td>12.2</td>
<td>87.8</td>
</tr>
<tr>
<td>1989–2000</td>
<td>21.2</td>
<td>78.9</td>
</tr>
<tr>
<td>2000–04</td>
<td>21.3</td>
<td>78.7</td>
</tr>
<tr>
<td>Memorandum:</td>
<td>25.6</td>
<td>74.4</td>
</tr>
<tr>
<td>Shares of total employment, 2000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Mishel, Bernstein, and Allegretto (2006).
a. Percentages may not sum to 100 because of rounding.
b. Individuals attending four years of college or more.
The trade argument

- **Is the effect of trade on wages quantitatively important?**

  A number of studies conducted during the 1990s concluded that the effects of North-South trade on inequality were modest.

<table>
<thead>
<tr>
<th>Study</th>
<th>Effect of trade with developing0 countries on skilled-unskilled wage ratio (percentage points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krugman (1995)</td>
<td>3</td>
</tr>
<tr>
<td>Lawrence (1996)</td>
<td>3</td>
</tr>
<tr>
<td>Cline (1997)</td>
<td>7</td>
</tr>
<tr>
<td>Borjas, Freeman, and Katz (1997)</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The final verdict on the actual effects of trade on wages has not yet been reached.