Overhead Labour and Skill-Biased Technological Change: The Role of Product Diversification

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Abstract

This paper tries to answer the question of why the technological change that has raised the wage-inequality didn’t accompany productivity growth by proposing an alternative mechanism of skill-biased technological change. This paper argues that skilled workers represent overhead labour and presents a model wherein skilled workers constitute a fixed input, required to produce a new product. Because skilled workers increase product variety rather than production quantity, skill-biased change doesn’t necessarily raise measured productivity. It is also predicted that skill-biased change will slow down in the long-run because the ratio of fixed to variable inputs cannot rise indefinitely.

Keywords: Skill Demand; product innovation; inequality; productivity

JEL classification: E24, J31, L1, O3, O4

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1 Introduction

The shift in labour demand favouring skilled workers has been found in many industrialized countries since the 1980s.\(^1\) The majority of the literature (e.g., Autor et al. [1998]; Katz and Murphy [1992]; Autor et al. [2008]) attributes this shift to technological change, referred to as the skill-biased technological change (SBTC) hypothesis.\(^2\) Although the literature has shown strong empirical evidence of the linkage between technology and skill-demand, the relationship between skill-biased change and aggregated labour productivity appears to be puzzling: skill-biased technological change didn’t always bring productivity growth. This paper tries to answer this question by proposing an alternative mechanism of skill-biased change, wherein skilled workers constitute overhead labour, in contrast with existing literature which typically assumes that both skilled and unskilled workers constitute variable labour inputs.

The most common analytical framework in the literature on skill-biased technological change, referred to by Acemoglu and Autor [2010] as the canonical model, is as follows. There are two types of labour inputs - skilled workers with university degree and unskilled workers with a less education level. Skill-biased change occurs if a technological change amplifies the productivity of skilled workers relative to unskilled workers. Both skilled and unskilled workers constitute variable inputs, which implies that a small increase in the employment of skilled workers increases output instantaneously. Therefore, an increase in the relative employment of skilled workers is expected to increase aggregate labour productivity. However, aggregate labour productivity growth slowed down in the 1980s, while wage premium from education rose the most rapidly during this period. The aggregate labour productivity began to accelerate again in the 1990s in the US, but the pace of skill-biased change began to slow down for the same period.

\(^1\)The most notable example is the US. However, the UK also experienced a sharp rise in the wage gap during this period. Although this trend was noted to be less strong in countries such as Germany and Sweden [Machin and van Reenen, 1998], the increase in the relative demand for skilled workers came to be identified as common to many industrialized countries.

\(^2\)Autor et al. [1998], for example, found that the share of college-graduate workers had risen faster in more computer-intensive industries.
In contrast, this paper assumes skilled white-collar workers are more likely to be overhead labour than blue-collar workers, and the employment of the skilled white-collar workers is not directly related with output level. The literature suggests that non-production workers are more likely to be overhead labour or constitute quasi-fixed input (Dunne et al. [1996]; Nekarda and Ramey [2013]; Gujarati and Dars [1972]; Hamermesh [1993]). The fact that skilled workers are more likely to constitute overhead labour has been largely ignored in theoretical literature on skill-biased technological change. Therefore, the ensuing question is what determines the demand for the skilled overhead labour. This paper proposes product diversification as such a determinant, although it may not be the only determinant.

The main assumption of the model presented in this paper is that introducing a new product requires a certain number of white-collar workers as a fixed input. For example, to develop a new product, a number of white-collar workers including engineers, designers, marketing experts, project managers and other administrative staff are needed irrespective of production volume. Therefore, the aggregate demand for the white-collar workers increases as product variety increases. This is consistent with the experience of the 1980s: a rapid increase in skill demand coincided with a surge in product variety as will be illustrated later in this paper.

The model features monopolistic competition with heterogeneous output goods, and product variety is endogenously determined via firm entry and exit. The fixed cost includes fixed capital cost as well as fixed labour cost. For example, firms may need to buy new machine tools, which are specific to a certain type of product, to initiate the production of a new product. A fall in the fixed capital cost (of product creation)

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3 In this paper, the terms "white-collar worker" and "non-production workers" are used synonymously.
4 For example, entering a foreign market may also increase the demand for overhead labour. However, entering a foreign market can be also understood as product diversification because the same type of goods sold in different countries are imperfect substitutes.
5 In the canonical model of SBTC, due to the assumption of homogeneous final good, the contribution of product innovation to skill-biased change is largely ignored. However, product innovation is important. According to Petrin and Warzynski [2012], 74% of total R&D expenditure is spent on product innovation in Denmark.
then encourages further product creation, which raises the aggregate demand for the fixed white-collar labour. Later in this paper, an empirical analysis is implemented and supporting evidence for the negative relation between the fixed capital cost and the skill demand are presented.

In my model, technological change raises skill-demand mainly via lowering the fixed capital cost required to produce a new product. The diffusion of FMS (Flexible Manufacturing System) since the late 1970s, which includes CAD(Computer-Aided Design) and CAM(Computer-Aided Manufacturing), is one example of such a technological change. As a result, product variety surged as is shown by Cox and Alm [1998] and this could have also raised the aggregate demand for the skilled fixed labour required for product creation. Such a transition from mass-production of standardized goods towards flexible production of customized goods was possible with the adoption of computers, which explains the positive relation between the computerization and skill-demand.

In contrast, the world wide diffusion of mass production of standardized goods via assembly lines during the post-World War 2 period may have had the opposite effect. The adoption of the assembly line has raised production efficiency in exchange for greatly increased fixed capital cost per product, leading to the mass-production of standardized products, thereby possibly lowering the growth of the demand for fixed white-collar labour, ceteris paribus. This explains why recent developments in information technology were skill-biased, while the adoption of assembly line was not. This statement serves as the central point of this paper, which intends to answer the question on what makes a specific technological change skill-biased.

My model generates novel predictions that help explain the puzzling discrepancies between the pace of technological change, aggregate productivity and skill-biased

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6 A fall in the fixed labour cost also increases product variety, but its net effect on skill-demand is uncertain because skill-demand per product declines in this case.

7 According to Milgrom and Roberts [1990], the adoption of FMS greatly reduced the capital cost of beginning production of new products. Under FMS, existing equipments and assembly lines could be flexibly utilised to produce new products.
change. Firstly, the employment share of white-collar workers is not necessarily positively related to the measured aggregate labour productivity. It is because white-collar workers mainly constitute fixed factors, which contributes not to production quantity but to product variety. Therefore, the current measure of productivity, which understates the consumer gain from product variety, is predicted to be negatively correlated with the employment share of white-collar workers, *ceteris paribus*. Therefore, this paper explains the puzzling fact that periods with supposedly strong skill-biased technological change, such as the 1980s, do not always reflect higher (measured) aggregate productivity growth. However, if the current measure of productivity is ideally modified to fully capture the benefit of product variety, such measures are predicted to be positively correlated with the employment share of white-collar workers.

Secondly, skill-biased change is predicted to slow down in the long-run without any corresponding reduction in the pace of technological progress. A technological change which lowers fixed capital cost, such as the diffusion of information technology, doesn’t reduce the fixed labour cost of product creation (thereby decreasing the share of fixed capital cost in the total fixed cost). As the share of fixed capital cost in the total fixed cost declines further, additional reduction of the total fixed cost (of product creation) becomes harder unless fixed labour cost declines as well. Although information technology might have lowered the fixed labour cost (as well as fixed capital cost), it lowers the employment of skilled fixed labour per product, leaving its net-effect on the aggregate skill-demand ambiguous. It is consistent with the empirical patterns, which indicate skill-biased change has begun to slow down recently (Autor et al. [2008]; Beaudry et al. [2013]) without any evidence that the progress of information technology slowed down in the 1990s, which was characterized as the decade of New Economy.

In sum, this paper presents an alternative mechanism of skill-biased technological change, and provides novel predictions which are consistent with the observed pattern.

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8However, this does not mean that income inequality will eventually stop rising. Skill-biased change is not the only driving force of income inequality, and other factors, such as rising inequality in capital income, can still raise income inequality without skill-biased change.
The remainder of the paper is structured in the following way: Section 2 explains the canonical model of skill-biased technological change and illustrates the role of product variety in skill-biased change. Section 3 presents the model and its implications. Section 4 concludes.

2 Overview

2.1 The canonical model of SBTC

In a large volume of literature on skill-biased technological change, a CES function with two types of labour inputs - skilled and unskilled labour - has been widely used to formulate the skill biased technological change:

\[
Q_t = \left[ \alpha_t (a_t N_{s,t})^\rho + (1 - \alpha_t) (b_t N_{u,t})^\rho \right]^{\frac{1}{\rho}}, \quad 0 < \rho < 1
\]  

Here, \( Q_t \) is the output at time \( t \), \( N_{s,t} \) is the labour input of skilled workers at \( t \), which is usually defined as the number of college graduate workers or white-collar workers. \( N_{u,t} \) is the labour input of unskilled workers, defined as the number of workers with lower education or blue-collar workers. Skill-biased technological change is represented either by an increase in \( a_t \) relative to \( b_t \) or by an absolute increase in \( \alpha_t \). Aggregate labour productivity is the weighted average of skilled and unskilled workers’ labour productivities. Therefore, skill-biased technological change is also supposed to raise aggregate productivity unless the decline in blue-collar labour augmenting technology is large enough to offset the rise in white-collar labour augmenting technology.

However, the skill-biased technological change did not come with aggregate productivity growth. Skill-biased technological change was supposed to have been the most rapid in the 1980s in the US. According to Card and DiNardo (2002), the puzzling fact is that the aggregate labour productivity was stagnant during the 1980s in the US.

\(^9\)Acemoglu and Autor [2010] referred to it as the ‘canonical’ model
as is shown in Figure 1. Moreover, the aggregate labour productivity growth began to accelerate again in the 1990s, but skill-biased change slowed down for the same period (Autor et al. [2008]).

Moreover, it is found in many countries that the aggregate productivity growth rate isn’t positively correlated with the employment share of high skilled workers. Table 1 shows the correlation coefficients between the aggregate labour productivity growth rate and the annual change in the employment share of high skilled workers, which refers to college graduates, for 12 OECD countries utilizing EUKLEMS data. Only countries with data available from 1980 are selected: Austria, Belgium, Denmark, Finland, France, Italy, Japan, Korea, Netherlands, Spain, UK and US.

One possible explanation for this puzzling result is that although a new technology raises productivity in the long-run, it requires learning cost, which temporarily lowers aggregate labour productivity growth during the transitional period after a technological revolution (Galor and Moav [2000]; Hornstein and Krusell [1996]). However, this paper offers an alternative explanation that the primary motivation of technological innovation during the 1980s might have been increasing product variety rather than increasing
Table 1: The correlation between the labour productivity growth rate and the change in the employment share of high skilled workers: 1981-2005

<table>
<thead>
<tr>
<th></th>
<th>Austria</th>
<th>Belgium</th>
<th>Denmark</th>
<th>Finland</th>
<th>France</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth</td>
<td>-0.004</td>
<td>-0.005</td>
<td>0.008</td>
<td>-0.058</td>
<td>-0.313</td>
<td>-0.181</td>
</tr>
<tr>
<td>Share</td>
<td>Japan</td>
<td>Korea</td>
<td>Netherlands</td>
<td>Spain</td>
<td>UK</td>
<td>US</td>
</tr>
<tr>
<td>Change</td>
<td>-0.641</td>
<td>-0.238</td>
<td>0.173</td>
<td>-0.035</td>
<td>0.248</td>
<td>-0.088</td>
</tr>
</tbody>
</table>

Note:
1) The data is from EU KLEMS 2008 database.
2) Countries with all data available from 1980 are included.

production quantity, which leads to increased productivity mismeasurement.\(^\text{11}\) Because the productivity slowdown was the result of the trade-off between the quantity and the variety, its negative impact on (measured) productivity is not transitional but permanent, in contrast with existing literature.

2.2 The evolution of product variety

Most of the existing literature on skill-biased technological change has largely focused on process innovation, while ignoring the role of product innovation in SBTC. However, product innovation accounts for a very significant part of R&D activities. For example, according to Petrin and Warzynski [2012], 74% of the total R&D expenditure is spent on product innovation in Denmark. Similarly, Lin and Saggi [2002] note that ‘approximately three-fourths of R&D investments by firms in the United States are devoted to product R&D’. However, the role of product innovation is creating new products, rather than increasing output for existing products.

Empirically measuring product variety is difficult. However, there have been some attempts, and it is known that product variety has dramatically increased since the late 1970s. According to Cox and Alm [1998], between the early 1970s and the late 1990s, the number of vehicle models available rose from 140 to 260, soft drinks from 20 to over 87, over-the-counter pain relievers from 17 to 141, running shoes from 5 to 285

\(^{11}\)Horstein and Krusell (1996) also suggested that the mismeasurement of GDP and productivity could have increased after the 1970s.
Figure 2: The number of vehicle models 1980-97

![Graph showing the number of vehicle models from 1980 to 1997.]

Source: "America’s Move to Mass customization", Cox and Alm [1998]

and PCs from 0 to 400. Figure 2 shows how the number of vehicle models evolved over time in the US since 1980.

Figure 3: The number of firms per capita in the US

![Graph showing the number of firms per capita from 1940 to 2000.]

Source: Greenwood and Uysal [2005]

Greenwood and Uysal [2005] noted that the number of trademark registrations rose
steadily since the 1980s, and the number of firms per capita also increased for the same period (Greenwood and Uysal [2005]) as illustrated in Figure 3. The trend of rising product variety since the 1980s coincided with the rising wage inequality of the 1980s. The question is what mechanism lies behind that coincidence.

There exists literature investigating the role of product innovation in SBTC. Xiang [2005] has argued that the introduction of new goods favours skilled labour because new goods are produced with more skill-biased technology than existing goods. Thoenig and Verdier [2003] proposed that competitive pressure from southern low-wage countries has induced northern countries to produce skilled-labour intensive goods because they are harder for southern countries to imitate. Sanders [2002] has argued that the development of new goods is skill-biased because production of new goods requires more skilled labour, who can flexibly deal with uncertainty of production, which is higher in the early stage of product life cycle. This literature commonly assumes that introducing new products increases skill demand because the production process of new goods is more skill-intensive than old goods.

Nevertheless, this is not necessarily true for every new good, especially for horizontal product differentiation. This paper will focus on the effect of horizontal product differentiation, wherein the new goods are not necessarily technologically more sophisticated, and therefore do not necessarily require more skilled workers in the production process. This paper is also closely related with Grossmann [2002], which claims that the role of skilled labour is increasing price-cost mark-up by differentiating the good from those of competitors. While Grossmann [2002] requires the mark-up ratio to rise continuously to explain the recent skill-biased change, my model does not need a rise

\[12\] Xiang [2005] attributes the surge in inequality in the 1980s to the availability of new products, "such as fiber optic cables, Windows series software, VCRs and soft contact lenses."

\[13\] This contrasts with Nelson and Phelps [1966] who argue that more educated workers are needed to adopt the latest vintage of production technology more quickly.

\[14\] One example is the development of the iPhone 4 white colour version by Apple. It is identical to the original black colour version except for the colour, and there is no technological improvement from the original. However, Apple spent a significant amount on R&D because making the iPhone whiter involves some technological difficulties, such as UV protection issues.
in the mark-up ratio to explain such changes.

3 Model

In the model presented in this paper, both goods and agents (workers) are heterogeneous. Goods are imperfect substitutes and people value consumption variety as well as quantity.\textsuperscript{15} To accommodate this 'love of variety', this paper utilises a Dixit and Stiglitz [1977] style monopolistic competition framework, wherein goods are imperfect substitutes and production of a good requires a fixed cost. While firms produce in a monopolistic competition market, individuals optimize their decisions - occupation and saving - to maximize their inter-temporal utility, which is formalized using a 2 period Overlapping Generation Model. The two distinctive assumptions of the model are: firstly, fixed labour input is biased toward white-collar workers (non-production workers), who are assumed to be more skilled workers\textsuperscript{16}; secondly, fixed cost includes not only the fixed labour cost but also fixed capital cost (the share of fixed capital cost in the total fixed cost falls possibly due to information technology).

3.1 Utility

The consumption bundle of a consumer comprises of different goods, which are imperfect substitutes to each other. Following the Dixit-Stiglitz framework, a CES aggregate of the consumption bundle, $x$, is defined as below:

$$x = \left( \int_0^N q(i)^\rho \, dt \right)^{\frac{1}{\rho}}, \quad 0 < \rho < 1$$

Then, the utility of a consumer, $u$, is a log of the CES aggregate, $x$:\textsuperscript{17}

\textsuperscript{15}In Krugman [1979b], the motivation of technological innovation is not producing the same goods more efficiently but producing new goods to gain more monopoly power.

\textsuperscript{16}In this paper, I assume that the term 'white-collar workers' is a synonym for the 'non-production workers', and that they are more skilled than production workers, while the term 'blue-collar workers' is synonymous with 'production workers'.

\textsuperscript{17}As it is a linear transformation, the solution for the optimization of $x$ is not affected.
\[ u = \ln(x) \]

Here, \( i \in [0, N] \) is the index of the product, where \( N \) is the maximum level of product variety in the economy. The constant \( \rho \) represents the substitutability between different goods, and the elasticity of substitution is \( \frac{1}{1-\rho} \). The utility depends on the diversity of goods as well as the total amount of goods, \( y \):

\[ y = \int_0^N q(i) di \]

\( y \) is the simple sum of all goods. Although \( y \) may reflect the effect of quality improvement (or vertical product differentiation)\(^{18}\), it is less likely to reflect the welfare gain from horizontal product differentiation, which is represented by the CES aggregate, \( x \). Current measures of output, such as GDP, are more likely to be the simple sum of goods, \( y \), than the CES composite of goods, \( x \), and do not fully account for the benefit from product variety.\(^{19}\) Therefore, an increase in product variety, \( N \), is likely to increase the underestimation of GDP.

### 3.2 Production

Each firm \( i \) produces using an identical technology following a Cobb-Douglas functional form, but production can begin only if the firm employs both fixed labour, \( l_{f,i} \), and fixed capital, \( k_{f,i} \), above minimum required levels (\( \bar{l}, \bar{k} \)):

\[
q_i = \begin{cases} 
A \cdot l_{v,i}^\alpha \cdot k_{v,i}^{1-\alpha}, & \text{if } l_{f,i} \geq \bar{l} \text{ and } k_{f,i} \geq \bar{k} \\
0, & \text{otherwise}
\end{cases}
\] (3)

Here, \( q_i \) is the production quantity of firm \( i \), \( l_{v,i} \) and \( k_{v,i} \) are variable labour and

\(^{18}\)For example, if the quantity of each product variety, \( q_i \), is quality-adjusted.

\(^{19}\)Although there has been a lot of effort to measure quality improvement in the GDP statistics, it is harder to measure the welfare gain from the horizontal product differentiation than from quality improvement.
capital inputs of the firm. The parameter $A$ represents the exogenous level of skill-neutral production technology, which augments all factor inputs proportionately.\textsuperscript{20}

Like typical monopolistic competition models, every firm produces a single product, and the number of products is equivalent to the number of firms. However, the firm here is different from firms in the real world, because most firms are multi-product firms in reality. Therefore, the firm in the model should be understood as a division or a production line within a firm, which is in charge of one product, rather than a firm in its entirety. Multi-product firms in the real world should be understood as a composite of multiple firms in this model.\textsuperscript{21}

**Composition of labour input**

A distinctive assumption of the model is that the fixed labour input, $l_f$, is biased toward non-production workers (white-collar workers), who are likely to be more skilled, while the variable labour input, $l_v$, is biased toward production workers (blue-collar workers) who are likely to be less skilled. For example, firms need to hire a certain number of white-collar workers, such as engineers, designers, project managers and marketing staffs, to develop a new product (in this model, to develop a new product is equivalent of creation of a new firm due to the assumption of single-product firm).\textsuperscript{22}

However, it is hard to know the exact share of fixed labour among white-collar and blue-collar labour. Therefore, it is assumed for simplicity that the employment of blue-collar workers, $l_{b,i}$, is equivalent to the employment of variable labour, $l_{v,i}$, and

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\textsuperscript{20}TFP growth is measured as the difference between the growth rate of output and the growth rate of total inputs which includes both fixed and variable inputs. Therefore, measured TFP growth deviates from the growth of technology, $A$, if the share of fixed inputs in total inputs change over time.

\textsuperscript{21}Moreover, even the same type of products of a firm sold in different markets (country, region or demographic group, etc.) should be interpreted as different products produced by different firms in this model. For example, one type of Starbucks coffee sold in the US is interpreted as a different product from the same type of Starbucks coffee sold in the UK because they are imperfect substitutes. They need to hire white-collar workers in the headquarters when they expand business into another country, region or demographic group.

\textsuperscript{22}It is assumed that firms must keep employing the fixed labour while it is operating. It might look rather strange considering that R&D staffs are needed only for the development process. However, after a new product, such as iPhone 5, is launched, the R&D staff are diverted to the development of the successor of that product, such as iPhone 6.
the employment of white-collar workers, $l_{w,i}$, is equivalent to the employment of fixed labour, $l_{f,i}$:

\[ l_{v,i} = l_{b,i} \]
\[ l_{f,i} = l_{w,i} \]

This is a strong assumption because it is likely that at least some white-collar labour constitutes variable input. However, this simplifying assumption can be justified if white-collar workers are more likely to constitute fixed labour than blue-collar workers. If so, relaxing the assumption won’t qualitatively change the results.

Although the employment of white-collar workers is assumed to be fixed for each product, the total employment of fixed white-collar labour in a multi-product firm is not fixed at all, and expected to increase in relation to the product range of the firm, which is likely to be positively correlated with the total output of the firm. Firms need to expand to more markets to sell more quantities of goods. According to Hottman et al. [2014], "variation in firm quality and product scope explains at least four fifths of the variation in firm sales." Therefore, the employment of white-collar overhead labour is still indirectly positively correlated with the output at a more aggregated level.

However, adjustment of product variety might require more time than adjustment of production quantity. Therefore, it is predicted that the aggregate demand for white-collar overhead labour adjusts to an output change slower than the demand for blue-collar production workers, which is consistent with empirical findings.\(^{23}\) However, such a rigidity of employment adjustment still remains although direct hiring and firing costs become zero. What this implies is that the rigidity of product creation/destruction contributes to employment rigidity alongside an inflexible labour market.

\(^{23}\)For example, Nekarda and Ramey [2013] finds that "the elasticity of the log of employment of nonproduction workers to GDP is positive and statistically significant and is about half of the elasticity of production workers with respect to GDP"
Firm’s problem

A Firm determines the levels of factor inputs and price of the final good to maximize its profit given factor prices:

$$\pi_i = (p_i - mc_i) \cdot q_i - f_{ci}$$  \hspace{1cm} (4)

Here, $\pi_i$ is the net-profit of firm $i$, $p_i$ is the price of its product and $q_i$ is the quantity of its product. $mc_i$ is its marginal product, which is constant, and $f_{ci}$ is its fixed cost.

In equation (4), the first term of the RHS refers to the gross-profit of firm $i$, which is the profit before paying for fixed cost, $f_{ci}$. Due to the symmetry condition, all firms set the same price, $p$:

$$p^* = \frac{mc}{\rho}$$

The price of goods, $p$, is normalized to 1 in this paper. The lower the substitutability between goods, $\rho$, the higher is the price-cost mark-up. Therefore, mark-up is constant unless the taste parameter, $p$, changes:

$$\text{mark-up} = \frac{p}{mc_i} = \frac{1}{\rho}$$

The total variable cost, $vc(q_i)$, is the sum of variable labour cost, which equals to the total wage for blue-collar workers, and variable capital cost:

$$vc(q_i) = mc \cdot q_i$$
$$= W_b \cdot l_i + r \cdot k_i^v$$

Here, $W_b$ is the wage for blue-collar workers, and $r$ is the interest rate. The fixed cost, $f_{ci}$, which consists of fixed labour cost as well as fixed capital cost is identical for

\hspace{1cm} 24\text{The marginal cost is constant because the Cobb-Douglas production function exhibits constant returns to scale and the factor prices do not change with the production level of individual firms.}
all firms:

\[ fc = W_w \cdot I + r \cdot \bar{k} \]

Here, \( W_w \) is the wage for white-collar workers, and \( \bar{I} \) is the minimum required level of fixed labour for each product, which is assumed to be identical for all firms. The employment level of white-collar workers for firm \( i \), \( I_i^w \), equals to \( \bar{I} \). Similarly, the employment level of fixed capital equals to \( \bar{k} \) for all firms. The interest rate, \( r \), is the same for both variable capital and fixed capital.

The employment of blue-collar labour is determined so that the value of marginal revenue product of labour (MRPL) equals the wage. Here, \( MRPL = MR \times MPL \).\(^{25}\)

Given the above CES-preferences shown in equation (2), \( MR = p \cdot \rho \). The price of the output, \( p \), is normalized to 1 and \( MRPL = \rho \cdot \frac{\partial q_i}{\partial l_i} = W_b \). Similarly, \( MRPK = \rho \cdot \frac{\partial q_i}{\partial k_v} = r \).

Due to the symmetry condition, every firm’s optimal level of employment is identical:

\( l_b = l_{b,i} \) and \( k_{v,i} = k_{v,i} \) for all firms \( i \).

**The ratio between fixed and variable costs**

The ratio between fixed and variable cost is endogenously determined via firm entry and exit, and plays a pivotal role in generating skill-biased change. Net-entry of firms increases the share of aggregate fixed cost in the economy, which increases the demand for skill, which will be shown later in more detail. Free entry is assumed, which implies zero net-profit in equilibrium (although the gross-profit remains positive):

\[ \pi_i^* = (p_i^* - mc) \cdot q_i^* - fc = 0 \]

Rearranging the zero-profit condition above gives the condition on the ratio between fixed and variable costs, \( f_v_i \):

\[ f_v_i = 1 - \frac{\rho}{\rho} \cdot vc(q_i^*) - fc = 0 \]

\(^{25}\)In a monopolistic competition market, \( MR < P \), unlike a perfect competitive market where \( MR = P \).
\[ f_{vi} = \frac{W_w \cdot \tilde{l} + r \cdot \tilde{k} (= fc)}{W_b \cdot l^b_i + r \cdot k^v_i (= vc)} ; \quad \frac{p^*_i - mc}{mc} = \frac{1 - \rho}{\rho} \]

\[ f_{vi} = \frac{p^*_i - mc}{mc} \iff \pi_i = 0 \]

\[ f_{vi} > \frac{p^*_i - mc}{mc} \iff \pi_i < 0 \]

\[ f_{vi} < \frac{p^*_i - mc}{mc} \iff \pi_i > 0 \]

Equation (6) shows that the ratio between total fixed cost and total variable cost, \( f_{vi} \), is determined by the price-cost mark-up ratio, \( \frac{p^*_i}{mc} \), which is again determined by the exogenous parameter \( \rho \), representing the substitutability between products. The Cobb-Douglas form implies that the ratio between variable labour cost and variable capital cost equals to \( \alpha \cdot \frac{1}{1 - \alpha} \).

\[ \frac{W_w \cdot \tilde{l} + r \cdot \tilde{k}}{\alpha} \cdot \frac{p^*_i - mc}{mc} \]

Equation (7) provides an intuitive explanation on the determinants of skill-biased change, which will be further developed into a general equilibrium framework in the remainder of this paper.\(^{26}\) The wage bill for white-collar workers, \( W_w \cdot \tilde{l} \), increases relative to that for blue-collar workers, \( W_b \cdot l^b_i \), under two conditions: Firstly, if the mark-up ratio, \( \frac{p^*_i}{mc} \), rises. Secondly, if the fixed capital cost, \( r \cdot \tilde{k} \), declines. These two predictions are essential for this paper, and more detailed empirical evidences supporting these are presented in the appendix of the paper.

Firms with higher mark-up ratios are predicted to have a higher share of non-production workers, \( ceteris paribus \), because those firms need smaller production quantities to recover fixed costs, leading to smaller batch sizes and larger share of fixed labour input (relative to variable labour input). Figure 4 shows a positive correlation between the wage-bill share of non-production workers and the mark-up ratio in the

\(^{26}\)Because the employment of the white-collar workers for a firm, \( \tilde{l} \), is assumed to be fixed, a skill-biased change is driven by a reduction in the employment of blue-collar labour, \( l^b_i \), due to a reduction in batch size. The gross-profit is proportional to the batch size, and the batch size decreases (via firm entry) until it is just enough to recover the fixed cost.
US manufacturing industries during the 1970-1992 period. However, a higher mark-up ratio raises skill-demand only if it reflects higher degree of product diversification, not a higher degree of monopoly due to entry barriers.

Firms with lower level of fixed capital cost, *ceteris paribus*, are also allowed to produce smaller batches of products to recover fixed cost, which implies higher relative wage-bill share of fixed labour (white-collar workers). However, the fixed capital cost is likely to have declined over time (relatively to other costs) for two reasons: Firstly, the rental rate of capital, \( r \), declining relative to the wage, lowers the fixed capital cost, \( r \cdot \bar{k} \), relatively to the fixed labour cost. Secondly, some technological innovations, such as the adoption of FMS (Flexible Manufacturing Systems), could have lowered the minimum required level of fixed capital, \( \bar{k} \), as will be explained more in detail later in this paper.

It is hard to measure the share of fixed capital in the total capital stock. However, we can utilise the presumption that capital structure is likely to be more fixed than capital equipment. In the Figure 5, it is shown that the share of the capital structure has decline in the US manufacturing industries between 1970 and 1992. This period coincides with the period of rising skill demand, which is consistent with the prediction.
Figure 5: The share of plant and building in the total capital stock in US manufacturing industries in 1970-92

source: NBER-CES manufacturing Industry database.

3.3 Occupational choice and supply of skill

Agents live two periods - they work and save when they are young, and they earn interest from their savings when they are old. When they begin to work in the first period, they choose whether to take education and become a skilled worker (white-collar workers) or a unskilled worker (blue-collar workers). The supply of skilled white-collar labour is determined by the optimization decisions of young workers who compare the wage premium for white-collar workers and the education cost required to become a white-collar worker.

In accordance with Caselli [1999], the subjective learning cost, $\sigma_{e,i}$, is assumed to be heterogeneous across workers and only those workers whose learning cost is lower than the wage premium from education goes to university. Therefore, those with a lower learning cost will become skilled white-collar workers, while those with a higher learning cost will become unskilled blue-collar workers. Following Caselli [1999], it is assumed, for simplicity, that each individual’s subjective learning cost, $\sigma_{e,i}$, follows uniform distribution so that $\sigma_{e,i} \in [0, \bar{\sigma}_e]$.\textsuperscript{27} $\bar{\sigma}_e$ is an exogenous parameter, which represents \textsuperscript{27}The subjective learning cost reflects not only tuition fee but also other opportunity costs (e.g. lost
the learning cost of the worker with the highest learning cost. However, the monetary value of the subjective learning cost is defined as $\sigma_{e,i} \cdot W_b$. The rationale behind this is that the amount of money needed to compensate for the subjective learning cost increases as the wage level of unskilled workers rises. Therefore, each young worker with a subjective learning cost, $\sigma_{e,i}$, chooses to go to university and become a white-collar worker if $W_w - W_b > \sigma_{e,i} \cdot W_b$, which determines the aggregate labour supply of skilled white-collar workers:

$$L^S_w = \frac{W_w - W_b}{\bar{\sigma}_e \cdot W_b} L$$  (8)

As the wage premium increases, the threshold level of subjective learning cost, below which it is optimal to go to university, increases accordingly. Therefore, the supply of skilled white-collar labour increases as the wage premium increases, but decreases as $\bar{\sigma}_e$ increases.

3.4 Competitive equilibrium

In this model, both the level of product variety and the relative demand for white-collar workers are endogenously determined given the levels of the factor endowments ($K$ and $L$) and a set of exogenous parameters, which represent technology, taste and education cost.

Definition. 1. A competitive equilibrium (dynamic) is a collection of sequences for consumption and price of each product, $\{c(i), p(i)\}_{t=0}^{\infty}$, variable and fixed factor inputs, $\{L_w, L_b, K_v, K_f\}_{t=0}^{\infty}$, the number of firms (products), $\{N_t\}_{t=0}^{\infty}$, wages, $\{W_w, W_b\}_{t=0}^{\infty}$, interest rate, $\{r\}_{t=0}^{\infty}$, for a set of exogenous parameters, $\rho$, $\bar{\sigma}_e$, $\bar{l}$ and $\bar{k}$, given the constant population, $L$ and the initial endowment of the total capital stock, $K_0$, which satisfy:

1. Each consumer optimally chooses consumption allocation, $c(i)_t$.  

labour income, lost leisure and personal effort) and other obstacles to education such as credit constraints.  

28The opportunity cost of education increases with the wage because the foregone labour income during the period of education increases.
2. Each worker optimally chooses whether to become a white-collar worker given the wage levels, \((W_w \text{ and } W_b)\), which determines the aggregate supplies of white-collar workers as is shown in equation (8).

3. Factor allocation, \((L_w, L_b, K_v \text{ and } K_f)\), solves the firm’s problem of equation (4) at each time period, \(t\).  

4. All goods and factor markets clear at each time period, \(t\).

5. The number of firms (products), \(N\), which determines both the factor allocations and the factor prices, is consistent with the zero-profit condition, at each time period, \(t\).

The solution for the competitive equilibrium will be explained in three steps, for convenience. Firstly, a set of equilibrium solutions that satisfy market clearing conditions for a given level of the number of firms (products) and factor endowments will be derived as functions of \(N, K\) and \(L\). Secondly, the number of firms (products) which makes the above equilibrium solution consistent with the zero profit condition will be derived. The solution for the number of firms (products), \(N\), depends on the level of the factor endowments of the period, \(K_t\) and \(L_t\). Thirdly, while the endowment of labour is assumed to be constant over time, the evolution of the total capital endowment, \(K_t\), will be derived based on two-period OLG model framework.

### 3.4.1 Market clearing conditions

Factor markets are cleared if the sum of the demand of individual firms for each factor input equals the supply (or endowment) of the same type of factor input in the whole economy. The demand for each type of workers must equal the supply of the same type

\[29\text{Here, the factor prices - } r, W_b \text{ and } W_w \text{ - are endogenously determined and functions of } N, \text{ while the price of good is normalized to 1.}\]
of workers:

\[ L_b^s = L_b^d = N \cdot l_b \]
\[ L_w^s = L_w^d = N \cdot l_w = N \cdot \bar{l} \]

\( L_b \) is the total employment of blue-collar workers in the economy, and \( L_w \) is the total employment of white-collar workers.

The total workforce, \( L \), is assumed to be given exogenously but is allocated endogenously between white-collar labour and blue-collar labour. Therefore, the sum of the employment of white-collar and blue-collar labour must be set to equal to \( L \).

\[ L_b + L_w = L \]

Similarly for capital:

\[ K_v = N \cdot k_v \]
\[ K_f = N \cdot k_f = N \cdot \bar{k} \]
\[ K_v + K_f = K \]

The total capital stock in the economy, \( K \), is exogenously given at each point in time, but endogenously allocated between variable part, \( K_v \) and fixed part, \( K_f \). However, I will show how capital stock accumulates endogenously over time in section 3.4.4.

A set of equilibrium levels of factor prices and allocations are analytically solvable and uniquely defined given the levels of factor endowments of the economy, \( L \) and \( K \), and the number of firms (products) in the economy, \( N \):
The equilibrium levels of the above endogenous variables varies with respect to different levels of \( N \). Hence, the profit, which is determined by the above variables in the equation (9), is uniquely determined by \( N \). It will be shown shortly after that there is a unique value of \( N \) resulting in zero profit.

### 3.4.2 The equilibrium number of products in the economy

The equilibrium number of products (firms) is determined by the zero-profit condition of equation (5), which is equivalent to the condition that\[
\frac{\text{total fixed cost}}{\text{total variable cost}} = \frac{p - mc}{mc}
\]
as is shown in the equation (6). The equilibrium ratio between the total fixed cost to the variable cost, \( f_v \), is a function of the number of products, \( N \):

\[
f_v(N) = \frac{W_w^*(N) \cdot \bar{l} + r^* \cdot \bar{k}}{W_b^*(N) \cdot l_b^*(N) + r^* \cdot k_v^*(N)} \tag{10}
\]

Here, a set of equilibrium levels of endogenous variables, \( W_w^* \), \( W_b^* \), \( k_v^* \), \( l_b^* \) and \( r^* \), depends on \( N \), while \( \bar{l}, \bar{k} \) and \( \rho \) are exogenous parameters, which are independent from \( N \). Substituting the equilibrium levels of the endogenous variables shown in (9) into (10) leaves only one endogenous variable, \( N \) with the exogenous levels of factor endowments, \( K \) and \( L \), and other exogenous parameters:

\[
f_v(N) = N \cdot \left\{ \alpha \cdot \frac{1}{L - N \cdot \bar{l}} \left( 1 + \sigma_e \frac{N \cdot \bar{l}}{L} \right) \cdot \bar{l} + (1 - \alpha) \frac{\bar{k}}{K - N \cdot \bar{k}} \right\} \tag{11}
\]
If \( f_v(N) \) is larger (smaller) than \( \frac{p - mc}{mc} = \frac{1 - \rho}{\rho} \), the net-profit becomes negative (positive), which results in net-exit (net-entry) of firms, reducing (increasing) the number of firms (products), \( N \). The equilibrium condition for \( N \) is:

\[
f_v(N^*) = \frac{1 - \rho}{\rho} \left( \frac{p - mc}{mc} \right)
\]  

By solving the equation (12) for \( N \), the equilibrium level of product variety, \( N^* \), is derived. Whether there is an unique solution for \( N \) is discussed in Lemma 1 as follows:

**Lemma 1.** There is a unique solution for \( N \), which satisfies the zero-profit condition as well as satisfying all market clearing conditions, leading to an unique solution in a competitive equilibrium.

**Proof.** The LHS of the equation (12), \( f_v(N) \), is a continuous and increasing function of \( N \). \( f_v(0) \to 0 \), while \( f_v(\frac{L}{\bar{l}}) \to \infty \). In contrast, the RHS of the equation is a constant representing the mark-up ratio (more precisely, price-cost mark-up minus one). Therefore, there must be a unique solution for \( N^* \) by the intermediate value theorem.

Lemma 1 shows that there is an unique solution for \( N^* \), which satisfies the zero profit condition. Then, corresponding levels of all other endogenous variables are derived accordingly, which solves for the competitive equilibrium. However, the value of \( N^* \) depends on the factor endowments, \( L \) and \( K \), and other values of exogenous parameters, \( \bar{l}, \bar{k}, \bar{\sigma}_e \) and \( \rho \). It will be illustrated how the competitive equilibrium solution responds to the either changes in the level of factor endowments or shocks to exogenous parameters in the following sections.

**Proposition 1.** A decrease in the levels of exogenous parameters, \( \bar{l}, \bar{k} \) and \( \bar{\sigma}_e \), increases the equilibrium level of product variety, \( N^* \).

**Proof.** Suppose the number of firms(products), \( N \), is initially at zero-profit equilibrium level, \( N^* \). Because \( \frac{\partial f_v}{\partial l} > 0 \), \( \frac{\partial f_v}{\partial k} > 0 \) and \( \frac{\partial f_v}{\partial \bar{\sigma}_e} > 0 \) for any positive values of \( \bar{l}, \bar{k} \) and \( \bar{\sigma}_e \),
any decreases in one of these parameters raises profit above zero. Therefore, this leads to the net-entry of firms seeking for positive profit until the number of firms(products) reaches $N^{**} > N^{*}$, where zero-profit condition is restored.

3.4.3 The effect of capital stock on product variety

Following competitive equilibrium solutions presented above, Figure 6 shows a simulation result which illustrates how the competitive equilibrium responds to a change in the total capital endowment of the economy, $K$.

![Figure 6: Evolution of product variety and skill demand in $K$](image)

The parameters assumed to derive the competitive equilibrium solutions shown in Figure 6 are: $L$ is normalized to 1 (with no population growth). The CES utility function is set so that $\rho = 0.7$, which implies that the mark-up ratio equals to approximately 1.43. $\bar{L}$ is 0.01, which means that the minimum required level of fixed labour input per product is 1% of the total labour endowment of the economy. $\bar{k} = 0.05$, which implies that the share of the minimum required level of fixed capital input per product in the total capital endowment is 5% when $K = 1$, but the share declines with capital accumulation. $\sigma_e = 2$, which means that the upper limit of the personal education cost is twice the wage for blue-collar workers, and the wage for white-collar workers must be twice the blue-collar workers to induce 50% of workers to choose university education and become white-collar workers.

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Capital accumulation increases total output while lowering the rental rate of capital (interest rate). Therefore, the fixed capital cost per firm, \( r \cdot \bar{k} \), falls as a result of capital accumulation. Therefore, an increase in \( K \) encourages further product creation by lowering the fixed capital cost of product creation. The demand for the fixed white-collar workers increases accordingly as product variety increases. The endowment of capital increases both product variety and the demand for the fixed white-collar labour. This is summarized as proposition 2:

**Proposition 2.** The effects of an increase in the level of total capital endowment, \( K \), are:

(a) The equilibrium level of product variety, \( N^* \), increases.

(b) The equilibrium levels of the employment share of white-collar workers, \( \frac{L_w}{E} \), and their wage premium over blue-collar workers, \( \frac{W_w}{W_b} \), increases.

**Proof.**

(a) Suppose the number of firms(products), \( N \), is initially at zero-profit equilibrium level, \( N^* \). In equation (11), \( \frac{\partial f_v}{\partial K} < 0 \), which means that an increase in \( K \) results in positive net-profit, leading to net-entry of firms thereby increasing \( N \), until the number of firms(products) reaches \( N^{**} > N^* \), where zero-profit condition is restored.

(b) An increase in \( K \) raises the equilibrium level of product variety \( N \). Equation (9) shows that both \( L_w^* \) and \( \frac{W_w^*}{W_b} \) are increasing functions of \( N \).

\( \square \)

As the total capital stock, \( K \), increases from \( K^1 \) to \( K^2 \), the number of products (firms), \( N \), increases from from \( N^1 \) to \( N^2 \), as shown in the bottom right quadrant of

\( ^{31} \)This increases output per firm (batch size) by increasing the variable capital input per firm, but the level of fixed capital input (in real terms) per firm remains unchanged.
Figure 6. Hence, the increase in product variety increases the employment share of white-collar workers, $L_w^L$, from $l^1$ to $l^2$, as shown in the bottom left quadrant of Figure 6. The increase in the employment share, due to an increase in product variety, increases the wage-premium, $\frac{W_w - W_b}{W_b}$, from $w^1$ to $w^2$, as shown in the top left quadrant of Figure 6. It is due to the fact that higher wage premium is needed to induce more people to invest in education and become white-collar workers.

However, the growth of $N$ decelerates as $K$ grows. It is because capital accumulation lowers only the capital part of the fixed cost, whose share in the total fixed cost decreases in relation to capital accumulation as shown in the top right quadrant of Figure 6. Hence, the total fixed cost of product creation decreases in relation to $K$, but at a decreasing rate. As a result, the growth of $N$, which is driven by the decrease in the fixed cost of product creation, eventually stops and converges toward a finite value, $N_{max}$.\(^{32}\)

**Proposition 3.** As $K$ goes to infinity, $N^*$ converges toward a finite value, $N_{max}$, where $N_{max} < \frac{L}{l}$. \(^{32}\)

**Proof.** In equation (12), the ratio between total fixed to total variable cost, $fv$, approaches infinity as $N$ approaches $\frac{L}{l}$. However, for any finite value of $N$, $fv$ is decreasing in $K$ and approaches towards a positive value as $K$ goes to infinity. Therefore, there always exists an equilibrium level of product variety, $N^*$, which satisfies zero-profit condition for any large value of $K$ and $N^* < N_{max} < \frac{L}{l}$. \(\square\)

As product variety has an upper limit, both the employment share of white-collar workers and the wage premium have upper limits as well. The corresponding upper limit of the employment share of white-collar workers is $l_{max}$ and that of the wage premium of white-collar workers is $w_{max}$.\(^{32}\)

**Corollary 1.** As $K$ goes to infinity, both the employment share of white-collar workers, $\frac{L_w}{L}$, and their wage premium over blue-collar workers, $\frac{W_w}{W_b}$, converge toward finite values.

\(^{32}\) $N_{max}$ corresponds to the equilibrium number of products (firms) if the share of fixed capital cost becomes zero.
Proof. As is shown in Proposition (3), $N$ converges toward a finite value, $N^{max}$, as $K$ goes to infinity. Equation (9) shows that both $\frac{L_w}{L}$ and $\frac{W_w}{W_b}$ are linearly increasing functions of $N$. Therefore, both $\frac{L_w}{L}$ and $\frac{W_w}{W_b}$ converges toward finite values as well. 

An important implication here is that skill-biased change will eventually slow down if it is driven only by a declining fixed capital cost (of product creation). There are other factors which induces skill-biased change, such as an increased mark-up, but no other factors in this model are likely to have as consistent trend as a decline in fixed capital cost. It is consistent with the empirical findings that skill-biased change has begun to slow down recently (Autor et al. [2008]; Beaudry et al. [2013]).

The other important implication here is that an increase in the level of capital stock can increase the demand for skilled white-collar workers. Therefore, this model replicates the well known skill-complementarity hypothesis.33 However, in contrast with the existing literature on skill-complementarity which argues that capital complement skilled workers directly in the production process, capital does not either complement white-collar workers or substitute blue-collar workers in the production process in this model.

3.4.4 Capital accumulation

In the above sections, competitive equilibrium solutions were derived for exogenously given levels of capital stock. However, this section explains how the level of capital stock evolves endogenously. The model follows the structure of the two periods OLG model, with two distinctive points: Firstly, there are two types of agents, white-collar and blue-collar workers, who differs in their wage, Secondly, the utility of consumption in each period depends not only on the total expenditure but also on the diversity of the consumption bundle. However, it will be shown later that the equilibrium path of

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33The empirical tests of the capital-skill complementarity hypothesis have shown mixed results. While Duffy et al. [2004] have reported a weak capital-skill complementarity, Willman et al. [2012] reject the hypothesis. Michaels et al. [2014] have found a complementarity of the skill demand with ICT capital stock but not with non-ICT capital stock.
capital accumulation remains largely identical to that of the standards OLG model (with homogeneous agent and good) in spite of these differences.

In the first period, type j agent earns labour income, $W_{jt}$. Although they differ in their wages, but their preferences are identical. They divide income into consumption, $C_{jt}$, and savings, $S_{jt}$. In the second period, they retire and live on the capital income from the savings.

$$\text{young} : C_{jt} + S_t = W_{jt}$$

$$\text{old} : C_{j,t+1} = (1 + r_{t+1}) \cdot S_{jt}$$

$j = w(\text{white-collar})$ or $b(\text{blue-collar})$

They maximize the inter-temporal utility by selecting the optimal level of consumption at time t, subject to the above budget constraint. However, each agent must choose not only how much money to spend but also choose which product to buy.

$$\max_{\{C_t\}} V(C_t) + \beta \cdot V(C_{t+1})$$

$$V'(C_t) = \beta \cdot (1 + r_{t+1}) \cdot V'(C_{t+1}) \quad (13)$$

Here, $V(C_t)$ refers to the utility from the consumption bundle which maximizes utility for a given level of the total consumption expenditure, $C_t = \int_0^N p(i) \cdot c(i) di$. Under symmetry condition, $p(i) = 1$ for all $i$, and $c(i) = \frac{C_t}{N_t}$ is identical for all $i$. The maximized level of utility, $V(C_t)$ is:

$$V(C^j) = \ln \left( \left\{ \int_0^{N_t} c(i)^p di \right\}^{\frac{1}{p}} \right)$$

$$= \ln \left( \frac{1}{N_t^{\frac{1}{p} - 1}} \right) + \ln \left(C^j\right)$$

Under the assumption that the utility is the log of the composite consumption bun-
dle, \( x \), the marginal utility of consumption is not affected by product variety, \( N \):

\[
\therefore V'(C^j_t) = \frac{1}{C^j_t}
\]  

(14)

By applying (14) into the Euler equation of (13), the optimal consumption levels of young workers (of type \( j \)) at \( t \) are:

\[
C^j_t^* = \frac{1}{1 + \beta} \cdot W^j_t
\]

The saving rate, \( \frac{s^j_t}{W^j_t} = \frac{\beta}{1 + \beta} \), is the same for every agent, and independent from the interest rate. One noteworthy feature is that the number of products, \( N_t \), does not influence the optimal saving decision.

**The law of the motion of capital**

It is assumed that capital stock fully depreciates in one period. Therefore, the total (real) capital stock in the economy at \( t + 1 \), \( K_{t+1} \) equals to the total (real) investment at \( t \), \( I_t \). However, a complication is that investment goods are heterogeneous, as well as consumption goods. Therefore, a natural question is that the composition of investment may matter as well as the total expenditure for all investment goods. If so, the aggregate saving may deviate from the aggregate investment depending on the way of aggregation. However, it will be shown below that it does not happen in this model, and the level of aggregate capital stock is independent of product variety in the model. It is due to two properties of the model: 1) the same type of good is used both for consumption and investment, 2) the level of aggregate capital stock is identical to the simple sum of individual capital goods, *ex post*. However, the aggregate capital stock is not the simple sum of individual goods *ex ante*, and constructed via Leontief style function:

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\[\text{This is because the increase in product variety only increases the level of utility without raising the marginal utility.}\]

\[\text{In this model, investment goods are not inherently different from consumption goods, and there is no separate investment good sector}\]

29
\[ K = \int_0^N \min(k(i)) \, di \]  

(15)

It is assumed that the level of aggregate capital stock, \( K \), is determined by the minimum level of individual capital goods. For example, the aggregate capital stock is zero if the amount of one type of capital good is zero. Therefore, in equilibrium, the amount of individual capital goods, \( k(i) \), is identical for every type of good. It also implies that the aggregate capital stock, \( K \), equals the simple sum of all types of individual capital goods, so that \( K = \int_0^N k(i) \, di \). Therefore, there is no gain from the diversity of capital good in the model.

Due to deceasing marginal utility, agents will divert the same portion of every type of consumption goods into investment goods.\(^{36}\) The price of investment goods, \( p_I \), is identical to the price of consumption goods, \( p \), so that \( p_I = p = 1 \). Therefore, \( S_t = \int_0^N p_I \cdot I_t(i) \, di = I_t \), and the total investment, \( I_t \), equals the total saving \( S_t \).\(^{37}\) Then, the total real capital stock equals the total saving of the previous period:

\[ K_{t+1} = S_t \]

(16)

\[ = \frac{\beta}{1+\beta} \left( W_t^b \cdot L_{b,t} + W_t^w \cdot L_{w,t} \right) \]

(17)

\( K_{t+1} \) is determined by the product of the saving rate and the sum of all agents’ labour income in the previous period. In the RHS of the equation, \( N_t, W_t^w, W_t^b, L_t^w \) and \( L_t^b \) are all increasing functions of \( K_t \). Therefore, \( K_{t+1} \) can be expressed as a function of \( K_t \), so that \( K_{t+1} = g(K_t) \), where \( g \) represents the law of motion of capital. In the steady state, \( K^* = g(K^*) \), and \( K^* \) is the steady state level of capital. The steady state level of \( N, W^w, W^b, L^w \) and \( L^b \) are all determined accordingly as functions of \( K^* \).

\(^{36}\)Because \( c(i) \) is the same for all \( i \), the ratio of investment good to consumption good, \( \frac{I(i)}{c(i)} \), is the same for all \( i \).

\(^{37}\)Therefore, there is no concern about the change in the relative price between investment goods and consumption goods in this model.
3.5 The effects of exogenous shocks

In the model, there are three types of shocks which raises skill demand: Firstly, the shock which lowers the level of fixed capital (required for product creation), Secondly, the shock which lowers the substitutability between goods by intensifying horizontal product differentiation, Thirdly, the shock which increases skill supply by lowering education cost. Suppose the economy is initially in a steady state at $t_1$, while the levels of population and technology remain constant. If there is a shock, the economy reacts to the shock and begins to converge towards a new steady state. It will be discussed how the dynamic competitive equilibrium responds to such an exogenous shock in the following section.

3.5.1 The effect of a shock in fixed capital cost

Product creation requires a certain amount of fixed capital investment for two reasons: Firstly, there is a minimum level of capital stock required for a firm or plant to operate; Secondly, there exists a certain amount of capital equipments which are specific to the production of a certain type of product. For example, when car manufacturers wanted to expand their product range, it used to require adding a new assembly line into existing plants, which involves substantial capital investment.

However, the minimum require level of such a fixed capital (of product creation), $\bar{k}$, is affected by technological change. For example, the adoption of the FMS (Flexible Manufacturing System) was mainly aimed at lowering the fixed capital cost of producing new products. The introduction of microprocessor in the late 1970s not only led to the proliferation of PC but also encouraged the adoption of CNC(Computer Numerical Control) machines, which enabled flexible manufacturing wherein new product can be produced in an existing assembly line with minimal change in equipment.\(^{38}\) Nowadays, it is common for a car manufacturer to product several types of cars in the same assem-

\(^{38}\) According to Mansfield [1993], 'the average year of first use of flexible manufacturing systems by major firms' is 1977.
bly line, and it is not needed to install a new assembly line to expand the product range, which significantly lowers the fixed capital cost of product creation (by lowering $\bar{k}$).

The fall in $\bar{k}$ can be also understood as a special sort of investment specific change, which augment the fixed capital. Suppose the decline in $\bar{k}$ has been driven by a growth in the latent technology, $v_t$, which augments the fixed capital, $k_f$:

$$\bar{k} = v_t \cdot k_{f,t}$$

A positive shock in the fixed capital-saving technology, $v_t$, enables product creation with less fixed capital per product, $k_{f,t}$. Figure 7 illustrates the effects of such a technology shock, which lowers $\bar{k}$. The initial steady state level of the total capital stock of the economy is $K^*$. After the shock occurs, the level of total capital stock and other variables converge toward the new steady state. The shock in $\bar{k}$ affects product variety, $N$. Then, both the employment share and the relative wage of white-collar workers respond to the change in the product variety.

The effect of the technological shock in $\bar{k}$ is twofold: Firstly, there is a contemporaneous effect, which occurs before the level of total endowment adjusts in response to the shock; Secondly, the shock affects capital accumulation and the change in the level of aggregate capital stock affects skill demand. The number of products (firms), $N$, increases for a given level of $K$, due to the fall in fixed capital cost, thus shifting the curve outward in the bottom right quadrant of Figure 7. Then, the increase in $N$ leads to an increase in the employment share of the white-collar workers, as shown in the bottom left quadrant. Such an increase in the employment share of white-collar workers, which is driven by a demand shift, leads to higher wage premium for white-collar workers as is shown in the top left quadrant. The contemporaneous effects of the shock in $\bar{k}$ are summarized in Proposition 4:

**Proposition 4.** For a given level of the total capital stock, $K$, the effects of a decrease in the minimum required level of fixed capital (of product creation), $\bar{k}$, are:
(a) The equilibrium level of product variety, $N^*$, increases for a given level of the total capital stock, $K$ (in the same period of the shock).

(b) The equilibrium levels of the employment share of white-collar workers, $\frac{L_w}{L}$, and their wage premium over blue-collar workers, $\frac{W_w}{W_b}$, increases (also in the same period as the shock).

Proof.

(a) Suppose the number of firms(products), $N$, is initially at zero-profit equilibrium level, $N^*$. Because $\frac{\partial f_v}{\partial k} > 0$ for any positive values of $\bar{k}$, any decreases in the parameter raises profit above zero. Therefore, this leads to the net-entry of firms seeking for positive profit until the number of firms(products) reaches $N^{**} > N^*$, where the zero-profit condition is restored.
(b) A decrease in \( \bar{k} \) raises the equilibrium level of product variety \( N \). Equation (9) shows that both \( L^*_w \) and \( \frac{w^*}{w_b} \) are increasing functions of \( N \).

The fall in \( \bar{k} \) allows more portions of capital endowment to be variable capital, which leads to increased output. Because saving is a linearly increasing function of output, the steady state level of the aggregate capital stock increases from \( K^* \) to \( K^{**} \). As the steady state level of the aggregate capital stock increases, the corresponding equilibrium level of product variety increases from \( N^* \) to \( N^{**} \) and the employment share of white-collar workers increase from \( l^* \) to \( l^{**} \). Then, the wage premium increases from \( w^* \) to \( w^{**} \) correspondingly. This indirect effect of the shock in \( \bar{k} \) is summarized in Proposition 5:

**Proposition 5.** The effects of a fall in the level of fixed capital per product, \( \bar{k} \), on the level of aggregate output, \( Y \), and the steady state level of the total capital stock, \( K \), are:

(a) \( Y \) increases in response to the shock, but the initial increase in \( Y \) is offset by the corresponding increase in \( N \).

(b) If \( Y \) increases, it raises the steady state level of capital stock, \( K^* \), towards a new level, \( K^{**} \).

**Proof.**

(a) Equation (9) implies that \( Y^* = A \cdot (L - N \cdot \bar{l})^\alpha \cdot (K - N \cdot \bar{k})^{1-\alpha} \). For a given level of \( N \), \( Y \) is a decreasing function of \( \bar{k} \). However, \( Y \) is a decreasing function of \( N \), which is a decreasing function of \( \bar{k} \) as is shown in Proposition 4.

(b) An increase in \( Y \) raises both the levels of consumption and investment, which equals to saving, proportionally, therefore the level of total capital stock in the next period, \( K_{t+1} \) increases correspondingly. As a result, the steady state level of capital stock, \( K^* \), changes to a new level, \( K^{**} \).
The crucial property of the model is that the positive effect of the fixed capital saving technological shock (which lowers $\bar{k}$) on the aggregate output, $Y$, is offset (at least partly) by the increase in product variety, which was induced by the same shock. If the number of firms (products) were fixed at the initial level, $N^*$, the aggregate output, $Y$, would rise to $Y'$, which is higher than the final steady state level, $Y^{**}$. Hence, the difference, $Y' - Y^{**}$, represents the lost (measured) output growth in exchange for the product variety growth. Because the level of aggregate employment is assumed to be fixed at $L$, this is equivalent to the lost (measured) aggregate productivity growth. However, the shock has an unambiguously positive effect on product variety, which contributes to consumer welfare.

If it is true that the massive computerization process since late 1970s mainly aimed at increasing the diversity of goods and services (rather than increasing the production quantities) by lowering the fixed capital cost of product creation, it is not surprising that its contribution to the output and productivity growth was not impressive.

3.5.2 Taste shock

In the model, the parameter $\rho$ of the CES aggregate in equation (2), which represents the substitutability between goods, determines the price-cost mark-up. If there is a taste shock which makes goods differentiated more than before, it lowers $\rho$, and the mark-up increases. This shock can be the result of more vigorous product innovation, marketing or advertising activities. The effect of such a shock is illustrated in Figure 8.

As the shock, which lowers $\rho$, occurs, the price rises relative to the marginal cost due to increased product diversification. Therefore, the shock raises the profit above zero, which leads to firm entry, and the number of firms increases until the zero-profit condition is restored. The curve in the bottom right quadrant of the figure, which represents the number of firms (products), $N_t$, shifts outward contemporaneously for a given
level of $K$. Both the employment share and wage premium of white-collar workers increase accordingly.

**Proposition 6.** For a given level of the total capital stock, $K$, the effects of a decrease in the substitutability of goods (a increase in the degree of product differentiation), $\rho$, are:

(a) The equilibrium level of product variety, $N^*$, increases for a given level of the total capital stock, $K$ (in the same period of the shock).

(b) The equilibrium levels of the employment share of white-collar workers, $\frac{L^w}{L}$, and their wage premium over blue-collar workers, $\frac{W^w}{W^b}$, increases (also in the same period as the shock).

**Proof.**
(a) Suppose the number of firms(products), $N$, is initially at zero-profit equilibrium level, $N^*$. As follows from equation (11) and (12), a decline in the substitutability between goods, $\rho$, raises the price of of goods so that $\frac{p-mc}{mc} > f_v(N^*)$, which raises profit above zero. Therefore, this leads to the net-entry of firms seeking for positive profit until the number of firms(products) reaches $N^{**} > N^*$, where zero-profit condition is restored.

(b) A decrease in $\rho$ raises the equilibrium level of product variety $N$. Equation (9) shows that both $L^*_w$ and $\frac{W^*_w}{W^*_b}$ are increasing functions of $N$.

However, the production quantity for each product (batch size) decreases, and variable inputs are diverted to fixed inputs to support product creation. Therefore, the aggregate output, $Y$, decreases, which leads to the decline in the level of savings and the level of total capital stock in the next period. The steady state level of capital stock decreases from $K^*$ to $K^{**}$, and it negatively affects the firm profit (via increased interest rate), which leads to firm exit. Therefore, the indirect effects of the shock partly offset the initial increase in product variety and skill demand by delaying capital accumulation.

**Proposition 7.** The effects of a decrease in the substitutability of goods, $\rho$, on the level of aggregate output, $Y$, and the steady state level of the total capital stock, $K$, are:

(a) A fall in $\rho$ lowers $Y$.

(b) The steady state level of capital stock, $K^*$, decreases towards a new level, $K^{**}$.

**Proof.**

(a) Equation (9) implies that $Y^* = A \cdot (L - N \cdot \bar{I})^\alpha \cdot (K - N \cdot \bar{k})^{1-\alpha}$. For a given level of $N$, a decline in $\rho$ has no effect on $Y$. However, $Y$ is a decreasing function of $N$, which is a decreasing function of $\rho$ as shown in Proposition 6.

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(b) A fall in $Y$ lowers both the levels of consumption and investment, which equals to saving, proportionally. Therefore the level of total capital stock in the next period, $K_{t+1}$ decreases correspondingly. As a result, the steady state level of capital stock, $K^*$, decreases to a new level, $K^{**}$.

3.5.3 Skill supply shock

In this model, the labour supply of white-collar workers is endogenously determined, and an increasing function of their wage premium over blue-collar workers as shown in equation (8). The decline in the education cost, $\bar{\sigma}_e$, increases the labour supply of white-collar workers for a given level of the wage premium, shifting the labour supply curve outwards. As it becomes cheaper to hire white-collar workers for product creation, firms’ fixed cost declines relative to their gross-profit, which leads to firm entry and an increase in product variety. Then, the increased product variety leads to an increase in the demand for white-collar workers. The effects of the shock is illustrated in Figure 9.

**Proposition 8.** For a given level of the total capital stock, $K$, the effects of a fall in the education cost, which is represented by the fall in $\bar{\sigma}_e$, are:

(a) The equilibrium level of product variety, $N^*$, increases for a given level of the total capital stock, $K$ (in the same period of the shock).

(b) The equilibrium levels of the employment share of white-collar workers, $L_w/L$, increases, but their wage premium over blue-collar workers, $W_w/W_b$, is not likely to increase.

**Proof.**

(a) Suppose the number of firms(products), $N$, is initially at zero-profit equilibrium level, $N^*$. Because $\frac{\partial f_v}{\partial \bar{\sigma}_e} > 0$ for any positive values of $\rho$, a decline in the parameter raises profit above zero. Therefore, this leads to the net-entry of firms seeking
Figure 9: The effect of a shock in education cost

for positive profit until the number of firms(products) reaches $N^{**} > N^*$, where the zero-profit condition is restored.

(b) A decrease in $\rho$ raises the equilibrium level of product variety $N$. Equation (9) shows that both $L^*_w$ and $\frac{W^*_w}{W^*_b}$ are increasing functions of $N$. However, $W^*_w = W^*_b \cdot \left(1 + \bar{\sigma}_e \frac{N \cdot \bar{I}}{L}\right)$ from the equation (9), and $\frac{W^*_w}{W^*_b}$ is an increasing function of $\bar{\sigma}_e$. Therefore, although $L^*_w$ increases unambiguously, the wage premium, $\frac{W^*_w}{W^*_b}$, does not.

Since the increase in the labour supply of white-collar workers encourages more diversified production, the portion of factor endowments allocated as fixed inputs (required for product creation) rises, which leads to a fall in the aggregate output, $Y$. As
income declines, saving and investment declines and the steady stated level of total capital stock declines from $K^*$ to $K^{**}$. Such a deceleration of capital accumulation partly offsets the initial increase both in product variety and skill demand.

**Proposition 9.** The effects of a fall in the education cost, $\bar{\sigma}_e$, on the level of aggregate output, $Y$, and the steady state level of the total capital stock, $K$, are:

(a) A fall in $\bar{\sigma}_e$ decreases $Y$ by increasing product variety, $N$, which leads to an unambiguous decline in $Y$.

(b) The steady state level of capital stock, $K^*$, decreases towards a new level, $K^{**}$.

**Proof.**

(a) Equation (9) implies that $Y^* = A \cdot (L - N \cdot \bar{l})^\alpha \cdot (K - N \cdot \bar{k})^{1-\alpha}$. For a given level of $N$, $\bar{\sigma}_e$ has no direct effect on $Y$. However, $Y$ is a decreasing function of $N$, which is a decreasing function of $\bar{\sigma}_e$ as is shown in Proposition 8.

(b) A decline in $Y$ lowers both the levels of consumption and investment, which equals to saving, proportionally, therefore the level of total capital stock in the next period, $K_{t+1}$ decreases correspondingly. As a result, the steady state level of capital stock, $K^*$, decreases to a new level, $K^{**}$.

After a positive skill supply shock (due to the fall in education cost), the wage premium of skilled white-collar workers over unskilled blue-collar workers declines, which is consistent with the prediction of the canonical model of skill-biased technological change.

Nevertheless, this rather puzzling prediction of my model that the spread of university education can actually lead to a slower growth relies on the strong assumption that the level of the skill neutral technology, $A$, which approximately represents TFP, is purely exogenous. If TFP is not exogenous and positively affected by the employment
of white-collar workers, increased skill supply might contribute to production quantity as well as to product variety. Moreover, even though university education does not contribute to GDP growth, it still contributes to consumer welfare by allowing more product variety to consumers. One important implication of my model is that the benefit of university education may be understated due to the limitation of current measures of GDP, which do not fully capture the welfare gain from product variety.

3.6 Matching empirical patterns

During the last decades, there has been structural changes in the evolution of skill demand, wage inequality and aggregate labour productivity in the US. However, other industrialized countries also experienced similar patterns.

Between the end of the second World War and the late 1970s, wage inequality did not show obviously upward trend. However, the pace of the technological innovations in those decades were not slower than in the following decades. We can remember the historical fact that the first landing of a human being on the Moon was in 1969. Furthermore, the aggregate productivity growth rate was higher in those periods than in the following decades. A key characteristic of production technologies during the period was mass production of standardized goods, which is represented by the assembly line and Taylorism management principles. This greatly improved production efficiency in exchange for decreased product variety. Moreover, an expansion of public support for education during the period could have lowered the average education cost, raising the supply of skilled white-collar workers. The combined effect could have led to higher productivity growth, lower growth of product variety and slower growth in wage premium for white-collar workers.

During the 1980s, the wage premium for skilled workers, who are mostly white-collar workers (non-production workers), rose while the employment share of them in the total workforce increased. In the literature, it is usually attributed to the progress
of information technology, such as the diffusion of computers (with micro-processors). The diffusion of computers enabled more flexible manufacturing and could have lowered the fixed capital cost of product creation. This would lead to an increase in product variety and the demand for white-collar workers, which is consistent with the observed pattern. However, aggregate labour productivity growth in the decade was not impressive in spite of the rapid diffusion of computers. What my model suggests is that a large increase in product variety in the 1980s could have offset the efficiency gains from computers because more factor endowments are diverted from variable inputs to fixed inputs, required for product creation. Moreover, if the diffusion of computers encouraged product differentiation by allowing more customized consumer goods to consumers via computerized design and marketing, it could have increased price-cost mark-up and further contributed to both increasing product variety and lowering (measured) productivity growth.

However, since the 1990s, the pace of skill-biased technical change has begun to slowdown. It is puzzling because there was no obvious sign of a slowdown in the pace of technological innovation in the 1990s.\footnote{For example, the world wide diffusion of the Internet was in the 1990s.} It is possible that the diffusion of PCs in the 1980s already lowered the fixed capital cost of product creation, which leaves less room for additional decline in the fixed cost of product creation.\footnote{Probably, it did not lowered the fixed labour cost of product creation as much. It is due to the fact that the cognitive and flexible nature of the tasks implemented by the white-collar workers, which are required for product creation, are hard to be substituted by information technology.} If so, the positive effect of the progress of information technology, which lowers the fixed capital cost of product creation, on skill demand declines although the pace of the technological change doesn’t slow down.

4 Conclusion

In this paper, I have presented a dynamic general equilibrium model to explain the role of overhead labour in skill-biased technological change. In the model, it is the
increasing share of the fixed labour inputs that increases demand for skill. It is because overhead labour is supposed to be biased towards white-collar workers, who usually have a higher education level.

This paper tried to answer the question of what makes a technology either skill-biased or unskill-biased. In this paper, the answer is that a technological change is skill-biased when it induces diversified production of customized goods, while it is unskill-biased when it induces mass-production of standardized goods as happened before the late 1970s.

This paper presents novel predictions. Firstly, while an increase in the employment share of white-collar workers is expected to increase (measured) labour productivity in the canonical model, the opposite is possible in the model presented in this paper. Secondly, it is predicted that there is an upper limit to the skill-biased change. Therefore, it is predicted that the growth of inequality between the white-collar workers and the blue-collar workers is likely to slow down in the long run.

References


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Mark Sanders. Product lifecycles and skill-biased technical change. Research Memorandum 014, Maastricht University, Maastricht Economic Research Institute on Innovation and Technology (MERIT), 2002.


Appendix A. Empirical evidences

Most of the analysis from this paper relies on equation (6), which predicts two main relationships under the assumptions of constant marginal cost and zero net-profit equilibrium: firstly, the ratio between the total fixed and the total variable costs is determined by the price-cost mark-up,\(^{41}\) and secondly, the share of the fixed labour cost in the total fixed cost is negatively related with fixed capital cost. Therefore, skill-demand is predicted to be positively related with the mark-up ratio, while it is predicted to be negatively related with the fixed capital cost. This section investigates if those key predictions of the model are consistent with empirical evidence.

It has been assumed in previous sections that all firms in the economy are homogeneous. However, in this section, this assumption is relaxed for empirical analysis. The between-industry differences in the wage-bill share of white-collar workers, mark-up ratio, and the share of fixed capital are utilised for empirical analysis. Therefore, the zero-profit condition of the equation (6) is rearranged for each industry \(i\):

\[
\frac{WB_{f,i} + r \cdot K_{f,i}}{WB_{v,i} + r \cdot K_{v,i}} = \mu_i \left( = \frac{P_i - MC_i}{MC_i} \right)
\]  

(18)

Here, \(WB_{f,i}\) refers to the total wage bill for fixed labour in industry \(i\), while \(WB_{v,i}\) is for variable labour. \(K_{f,i}\) refers to the fixed capital stock in the industry \(i\), while \(K_{v,i}\) is for variable capital. \(r\) refers to rental rate of capital.

Fixed cost and mark-up

We now test whether the prediction of the equation ((6)) that the ratio of the total fixed to total variable cost is determined by mark-up ratio. However, we cannot directly observe how much of the total labour force is constituted by fixed or variable labour.

In this paper, a strong assumption that white-collar labour is an entirely fixed input and

\(^{41}\)To be precise, it equals to \(\mu = \text{mark-up} - 1\). While mark-up is the ratio between the price and the marginal cost, \(\mu\) is the ratio between the gross-profit and the marginal cost.
blue-collar labour is an entirely variable input was made earlier.\textsuperscript{42} If that assumption is true, equation (18) then becomes:

\[
\frac{WB_w + r \cdot \hat{s}_f \cdot K}{WB_w + r \cdot (1 - \hat{s}_f) \cdot K} = \hat{\mu}
\]

(19)

Here, \(WB_w\) is the total wage bill for white-collar workers, and \(WB_b\) is the total wage bill for blue-collar workers. \(\hat{s}_f\) is the share of fixed capital in the total capital stock, \(k\). These values are recovered using US manufacturing data over 1970-1992, and the values of \(\hat{\mu}\), which represent the ratio of fixed to variable costs, have been constructed. Because \(\hat{\mu}\) is predicted to be the same as the price-cost mark-up ration, \(\mu\), these two values are compared.

The data on the wage bill for both production workers and non-production workers and capital stock comes from the NBER-CES Manufacturing Industry Database, which is based on the ASM (American Survey of Manufacturers). The interest rate used here is the Baa rated corporate bond rate, which comes from the FRB (Federal Reserve Board). The inflation rate is from the U.S. Bureau of Economic Analysis.

Data on the mark-up is from Oliveira Martins et al. [1996]. In that study, mark-up ratios for 36 manufacturing industries in the US are estimated over 1970-1992 utilizing the method of Roeger [1995], assuming that the mark-up ratio is constant over the period.\textsuperscript{43} The list of mark-up ratios for each industry and the method of estimation are shown in the Appendix. The rental rate of capital, \(r\), is derived following Oliveira Martins et al. [1996]:

\[
r = ((i - \pi) + \delta) \cdot p_k
\]

(20)

Here, \(i\) is the nominal interest rate, which is equivalent to the Baa rated corporate bond rate. \(\pi\) is the inflation rate, and \(\delta\) is the depreciation rate, which is set to 5% per

\textsuperscript{42}However, the term “fixed” means that it is fixed for a product (or a single-product firm), but it is not fixed at more aggregated level.

\textsuperscript{43}However, not all industry groups in Oliveira Martins et al. [1996] showed significant estimates for the mark-up ratio, and only the estimates for 26 industry groups amongst them are used in this study.
year. $p_k$ is the price index of the investment good.

One problem is that the share of fixed capital in the total capital stock is unobservable. To deal with that issue, the share of capital structure (plant and building) in the total capital stock is used as a proxy for the share of fixed capital. The rationale is that plants and buildings are usually adjusted more rigidly than equipment or vehicles. For example, at least one head-quarter building and one factory are needed to establish a firm. Then, it is possible to increase the stock of equipment without building another factory (upto a certain level). However, this is a rough measure because certain equipment or vehicles might be fixed capital as well.\footnote{For example, it is likely that there is a minimum level of capital equipment required to produce a product, which does not fall to zero as the production volume declines toward zero.}

Figure 10: Mark-up ratio vs fixed to variable costs ratio

\[ \mu \text{ and } \hat{\mu} \text{ are compared in Figure 10. A positive correlation is found between them. Industries with a higher ratio of fixed cost, such as Office & Computing, Drug & Medicine and Radio, TV & Communications, are also shown to have a higher mark-up ratio. Those with a lower share of fixed cost, such as Food Products and Petrol Refineries, are shown to have a lower mark-up ratio.}

However, some industries, especially the tobacco industry, show a higher mark-up
ratio, $\mu$, than the ratio of fixed to variable costs, $\hat{\mu}$. There are three possible reasons for the difference: Firstly, this difference may be due to the existence of excess profit from market power, which allows firms to charge higher prices than necessary to recover fixed costs. Secondly, although it is assumed that the share of fixed capital is equivalent to the share of capital structure (building and plant), some capital equipment may constitute fixed inputs as well, which causes a downward bias in the estimated share of fixed capital, $\hat{s_f}$ and the ratio of fixed to variable costs, $\hat{\mu}$. Thirdly, if the assumption of constant marginal cost is violated and the actual marginal cost is decreasing in scale, it also lowers the ratio of the total fixed to the total variable costs below the mark-up ratio.

Figure 11: Observed wage-bill share vs predicted share

It is also possible to derive the predicted wage-bill share of white-collars (in the total wage-bill including both white-collar and blue-collar workers) from equations (18) and (19). Then, the observed wage-bill share of white-collar workers is compared with the predicted wage-bill share of the white-collar workers in Figure 11. These two are supposed to be the same if $\hat{\mu}$ is identical to $\mu$.

For the same reasons as the ratios of fixed cost to variable cost (supposed to be the same as $\mu$) are lower than $\mu$, the observed wage-bill shares of white-collar workers are lower than the predicted wage-bill share of the white-collar workers. The fact that
the predicted wage-bill share exceeds 100% for some industries, which is impossible in reality, implies that some of the predicted wage-bill shares are overestimated. However, the observed wage-bill shares of white-collar workers are shown to be positively correlated with the predicted wage-bill shares of fixed white-collar labour.

**The ratio between equipment and structure**

In the above sections, it is inferred that the share of fixed capital cost has declined over time. As this happens, the share of capital structure, which is more likely to be fixed than capital equipment, is expected to decline.

Given the ratio between fixed and variable costs, the wage-bill of white-collar workers is expected to be negatively related with fixed non-labour cost, while that of blue-collar workers is negatively related with variable non-labour cost. Therefore, the share of capital structure in the total capital stock is expected to be negatively correlated with the wage-bill share of white-collar workers (In other words, the share of equipment is positively correlated with the skill-demand.).

| Table 2: Correlations with the white-collar wage-bill share |
|---------------------------------|----------------|----------------|
|                                 | \( \frac{W^B W}{WB} \) | mark-up | \( \frac{K_s}{K} \) |
| \( \frac{W^B W}{WB} \)        | 1              | -       | -               |
| mark-up                        | 0.4565         | 1       | -               |
| \( \frac{K_s}{K} \)           | 0.0562         | 0.2020  | 1               |

Obs: 15327

Table 2 shows the correlations between the wage-bill share of white-collar workers, \( \frac{W^B W}{WB} \), the mark-up ratio and the share of capital structure, \( \frac{K_s}{K} \). The data again comes from the NBER-CES Manufacturing Industry Database, covering the period from 1970 to 1992. Each observation corresponds to a 6-digit NAICS industry’s annual average values.

It is found that the share of capital structure, \( \frac{K_s}{K} \), is slightly positively correlated with the white-collar wage-bill share (the coefficient is 0.0562). However, \( \frac{K_s}{K} \) is also
positively correlated with the mark-up (coefficient: 0.2020), which is strongly positively correlated with the wage-bill share of white-collar workers, $\frac{W_B^W}{W_B}$ (coefficient: 0.4565). Therefore, the positive correlation between the share of capital structure and the wage-bill share of white-collar workers does not necessarily reflect a direct causality.

Table 3: The effect of the share of capital structure on skill demand: 1970-92

<table>
<thead>
<tr>
<th></th>
<th>(1) OLS</th>
<th>(2) OLS</th>
<th>(3) FE</th>
<th>(4) BE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{K_s}{K}$</td>
<td>0.069***(0.013)</td>
<td>0.008(0.013)</td>
<td>-0.284***(0.007)</td>
<td>0.121*(0.070)</td>
</tr>
<tr>
<td>$\frac{\Delta W}{\Delta K}$</td>
<td>-</td>
<td>-0.023***(0.001)</td>
<td>0.009***(0.001)</td>
<td>-0.031***(0.007)</td>
</tr>
<tr>
<td>const.</td>
<td>0.324***(0.006)</td>
<td>0.380***(0.007)</td>
<td>0.476***(0.003)</td>
<td>0.338***(0.036)</td>
</tr>
<tr>
<td>Obs.</td>
<td>10,626</td>
<td>10,626</td>
<td>10,626</td>
<td>10,626</td>
</tr>
</tbody>
</table>

Note:
1) The dependent variable is $\frac{W_B^W}{W_B}$, the wage-bill share of white-collar workers in the industry
2) $\frac{K_s}{K}$: the ratio of capital structure to total capital stock
3) ***: significant at 1% error level

To distinguish the direct effect of the share of fixed capital (structure) from its indirect effect via its positive correlation with the mark-up, we should ideally include the mark-up ratios as a control variable, but the data on the mark-up ratio is not available at a more disaggregated level. Therefore, panel analysis is implemented with the assumption that the mark-up ratios are not time-varying (or at least less time-varying than other variables). The results are shown in Table 3. In the first and second column, OLS results are shown. The coefficient on the share of capital structure is shown to be positive and significant. However, the coefficient turns to insignificant once the ratio of the total capital stock to the value added output, $\frac{K}{Y}$, is included.

Moreover, the coefficient becomes negative and significant in the fixed effect result, shown in the third column of the table. In contrast, the coefficient is positive but weakly significant (at 10% error level) in the between effect result shown in the fourth column of the table. These contrasting results imply that the correlation between the share of capital structure, which is more likely to be fixed than capital equipment, and skill demand is negative within an industry, but positive between industries. Because the positive correlation between the unobserved level of mark-up ratio and the share
of capital structure is supposed to be better controlled in the fixed effect result, the above-mentioned results are consistent with the key prediction of my model that the employment share of white-collar workers is negatively related with the share of fixed capital.

**Appendix B. About mark-up ratio data**

The mark-up ratio data comes from Oliveira Martins et al. [1996], who utilised Roeger [1995]’s method. Roeger [1995] utilises the gap between TFPs measured by different methods. Typically, TFP is estimated by calculating Solow residual as below:

\[
SR = \Delta q - \alpha \Delta l - (1 - \alpha) \Delta k
\] (21)

Here, SR refers to the Solow residual, and \(\alpha\) is the share of labour income in the output. \(\Delta l\), \(\Delta k\), \(\Delta q\) are the differences in the logs of labour input, capital input and output. The contribution of each factor in production is equal to its income share under the assumption of perfect competition.

However, Roeger [1995] showed that TFP can also be estimated using a price-based Solow residual. It is defined by the difference between the increase in the weighted average of the factor price and the increase in the price of output as below:

\[
SRP = \alpha \Delta w - (1 - \alpha) \Delta r - \Delta p
\] (22)

Here, SPR refers to the price-based Solow residual. \(\Delta w\), \(\Delta r\), \(\Delta p\) are the difference in the logs of wage, rental rate of capital and output price. When there is a positive technology shock, the output price rises less than the increase in the factor prices as the factors are consumed less due to the productivity improvement. In theory, under the assumption of perfect competition, TFPs estimated by both methods should be the same in theory. However, they are rarely identical in practice.
The point is that the labour’s income share of output is not an accurate measure of labour’s contribution to production under imperfect competition. The exact contribution of labour is equal to its income share in the marginal cost, which is lower than the price. Therefore, labour’s income share of output underestimates the contribution of labour and overestimates the contribution of capital under imperfect competition. As a result, both Solow residuals are biased, but in different directions. From the gap between these two types of Solow residuals, the mark-up ratio can be estimated as below:

\[ SR_t - SRP_t = B \Delta x_t + \epsilon_t \]  \hfill (23)

\[ \Delta x_t = (\Delta y_t - \Delta k_t) + (\Delta p_t - \Delta r_t) \]

Here, B is the Learner index defined as \( B = \frac{P - MC}{P} \), or \( B = 1 - \frac{1}{\mu} \), where \( \mu \) is the mark-up ratio. The mark-up ratio is derived by estimating B in equation (23). However, Oliveira Martins et al. [1996] modify Roeger’s method to incorporate material inputs in equation (23). The estimation equation used in Oliveira Martins et al. [1996] is:

\[ \Delta y_t = B \cdot \Delta x_t + \epsilon_t \]  \hfill (24)

where,

\[ \Delta y_t = (\Delta q + \Delta p) - \alpha \cdot (\Delta l + \Delta w) - \beta \cdot (\Delta m + \Delta p_m) - (1 - \alpha - \beta) \cdot (\Delta k + \Delta r) \]

\[ \Delta x_t = (\Delta y_t - \Delta k_t) + (\Delta p_t - \Delta r_t) \]

Oliveira Martins et al.(1996) also adjust for the effect of indirect taxes on the estimated mark-up as below:

\[ \mu = \frac{\mu^e}{1 + \tau} \]

Here, \( \mu^e \) is the estimated mark-up ratio, and \( \tau \) is the indirect tax rate. Estimated
mark-up ratios from Oliveira Martins et al. [1996] are shown in Table 4. The industrial classification system they use in Oliveira Martins et al. [1996] is ISIC rev.2. Data on payment, capital stock and material cost are based on NAICS 97 classification in this paper. Therefore, only ISIC rev.2 industry groups with a clear correspondence to NAICS 97 classifications are used for estimation.

Table 4: The mark-up ratio in the US manufacturing, 1970-1992

<table>
<thead>
<tr>
<th>Sector name</th>
<th>ISIC rev.2</th>
<th>Sector (Naics 97)</th>
<th>mark-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Products</td>
<td>3112~</td>
<td>311000 ~ 312000</td>
<td>1.05</td>
</tr>
<tr>
<td>Beverages</td>
<td>3130~</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tobacco products</td>
<td>3140~</td>
<td>312200 ~ 313000</td>
<td>1.56</td>
</tr>
<tr>
<td>Textiles</td>
<td>3210~</td>
<td>313000 ~ 313000</td>
<td>1.08</td>
</tr>
<tr>
<td>Wearing apparel</td>
<td>3220~</td>
<td>315000 ~ 316000</td>
<td>1.10</td>
</tr>
<tr>
<td>Leather products</td>
<td>3230~</td>
<td>316000 ~ 321000</td>
<td>1.08</td>
</tr>
<tr>
<td>Wood products</td>
<td>3310~</td>
<td>321000 ~ 322000</td>
<td>1.22</td>
</tr>
<tr>
<td>Furniture</td>
<td>3320~</td>
<td>333000 ~ 339000</td>
<td>1.06</td>
</tr>
<tr>
<td>Paper products &amp; Pulp</td>
<td>3410~</td>
<td>322000 ~ 323000</td>
<td>1.13</td>
</tr>
<tr>
<td>Printing &amp; Publishing</td>
<td>3420~</td>
<td>323000 ~ 324000</td>
<td>1.19</td>
</tr>
<tr>
<td>Industrial chemicals</td>
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<td>325130 ~ 325400</td>
<td>1.18</td>
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<tr>
<td>Drugs &amp; Medicines</td>
<td>3522~</td>
<td>325400 ~ 325500</td>
<td>1.44</td>
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<tr>
<td>Chemical products</td>
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<td>325500 ~ 326000</td>
<td>1.26</td>
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<tr>
<td>Petroleum refineries</td>
<td>3530~</td>
<td>324110</td>
<td>1.03</td>
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<tr>
<td>Petroleum &amp; Coal products</td>
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<td>324121 ~ 324199</td>
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<td>Rubber products</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>Plastic products</td>
<td>3560~</td>
<td>326000 ~ 326200</td>
<td>1.07</td>
</tr>
<tr>
<td>Pottery &amp; China</td>
<td>3610~</td>
<td>327000 ~ 327200</td>
<td>1.09</td>
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<tr>
<td>Glass products</td>
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<td>327200 ~ 327300</td>
<td>1.17</td>
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<tr>
<td>Non-metal products</td>
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<td>327300 ~ 331000</td>
<td>1.18</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
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<td>331000 ~ 331300</td>
<td>1.10</td>
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<tr>
<td>Non-ferrous metals</td>
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<td>331300 ~ 332000</td>
<td>1.14</td>
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<td>Metal products</td>
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<td>332000 ~ 333000</td>
<td>1.09</td>
</tr>
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<td>Office &amp; Computing mach.</td>
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<td>334000 ~ 334200</td>
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<td>Machinery &amp; Equipment</td>
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<td>333000 ~ 334000</td>
<td>1.06</td>
</tr>
<tr>
<td>Radio, TV &amp; Comm. equip.</td>
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<td>334200 ~ 334300</td>
<td>1.40</td>
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<td>Electrical apparatus</td>
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<td>-</td>
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<tr>
<td>Shipbuilding &amp; Repair</td>
<td>3841~</td>
<td>-</td>
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<td>Railroad equipment</td>
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<td>-</td>
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<tr>
<td>Motor vehicles</td>
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<td>336000 ~ 336400</td>
<td>1.09</td>
</tr>
<tr>
<td>Motorcycle &amp; Bicycles</td>
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<td>336991</td>
<td>1.13</td>
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<tr>
<td>Aircraft</td>
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<td>-</td>
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<tr>
<td>Other transport equipment</td>
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<td>-</td>
</tr>
<tr>
<td>Professional goods</td>
<td>3850~</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other manufacturing</td>
<td>3900~</td>
<td>339000 ~ 340000</td>
<td>1.08</td>
</tr>
</tbody>
</table>