

Education, Technology and the Wage Structure in Taiwan, 1979-1998

James P. Vere

Princeton University

October 9, 2001

Abstract

In this paper we study the wage structure effects of Taiwan's compulsory education policy, to which we attribute substantial changes in the educational composition of the population, and Taiwan's science and technology development policy, to which we attribute changes in the complementarity of skilled and unskilled labor. In the first part, we quantify these changes and describe differences in educational attainment in Taiwan across birth cohorts. In the second part, we use regression analysis to describe changes in Taiwan's wage structure, decomposing the wage return to education into two components, a fixed birth cohort component and a variable time component. We find evidence for general equilibrium effects reducing the wage return to higher education for better-educated cohorts. In the third part, we present estimates of the elasticities of complementarity between skilled and unskilled labor in Taiwan and evidence that these elasticities have changed over the time period studied in step with the new technology. We conclude that both general equilibrium effects and structural changes in production are needed to account for the observed changes in Taiwan's wage structure.

We are grateful to Anne Case and Christina Paxson for numerous helpful comments. We also thank the Social Sciences Research Council for financial support.

1 Introduction

It is generally recognized that the returns to education in developing countries are different from the returns to education in more developed economies. These differences are most often attributed to compositional differences in both the supply of and the demand for educated labor. At the same time, however, the effects of changes in the educational attainment of a country's population and technological advances in that country's industries on its wage structure are not well understood.

In many ways, Taiwan presents an ideal case with which to shine light on the question of the effects of increased educational attainment and industrial development on the wage structure. Not only did the educational distribution of Taiwan's population undergo substantial changes from 1979 to 1998, but also the character of production in Taiwan's manufacturing sector, under an aggressive science and technology development policy, changed rapidly over the same time period. Additionally, detailed microdata on Taiwan's labor force is available for every year from 1979 onward.

This study is not the first to take note of this and seek to measure these effects. The study by Gindling, Goldfarb and Chang (1995) is the first of which we are aware. Using the data from the May supplement of Taiwan's Labor Force Surveys through 1991, they observe a generalized decline in the wage return to education for graduates with a lower secondary qualification or higher. Further, they observe that the tertiary returns to education exceeded the secondary returns to education in Taiwan, which is an unusual finding for a developing country (c.f. Psacharopoulos 1989). They speculate that these trends resulted from a combination of an increased supply of educated graduates and exogenous skill-biased technical change increasing the demand for these graduates, but call for further research on the subject. Clark and Hsieh (2000) study Taiwan's compulsory education policy with similar data and an eye toward using year of birth as an instrument to measure the return to a year of schooling in Taiwan. They find that doing so generates IV estimates of the return to education that are significantly lower than the corresponding OLS estimates, which they argue is because of the significantly greater supply of educated graduates in Taiwan after the compulsory education policy in Taiwan took effect.

This paper substantiates these findings and offers an analytical framework to explain changes in the wage structure in Taiwan through both general equilibrium supply effects and technical change altering the

character of production in Taiwan's manufacturing sector. We put forth that the key to resolving the wage structure effects of an education policy within the framework of industrial development lies in the complementarity of skilled and unskilled labor. Complementarity is important because it will predict the wage response of unskilled labor to a large increase in the supply of educated graduates brought about by a large-scale education policy. If skilled and unskilled labor are complements, increasing the quantity of skilled workers employed will drive up the wages of unskilled workers. But if they are substitutes, increasing the quantity of skilled workers employed will drive the wages of the unskilled down. The environment of industrial development matters because the production technology employed plays a large part in determining whether skilled and unskilled laborers are complements or substitutes in the first place.

This paper is divided into four sections. The first describes the education policies of Taiwan leading up to this time period and Taiwan's industrial development policies for these two decades, paying particular attention to the outcomes of these policies across different birth cohorts. The second section uses regression analysis to quantify changes in Taiwan's wage structure from 1979 to 1998 among birth cohorts and educational groups. In the third section, we impose a production function and use this production function to calculate the elasticities of complementarity among different types of labor over time. Finally, in the fourth section we summarize our results and draw conclusions about how Taiwan's education policy affected the wage structure in the context of its technology development policy.

2 Taiwan's Education and Science & Technology Policies

In this section we describe the implementation and outcomes of Taiwan's education and industrial development policies. We will make two main points: that the supply of educated graduates increased substantially over the time period from 1979 to 1998, particularly within younger cohorts; and that changes in manufacturing processes during this time were primarily changes from labor-intensive to labor-saving technologies. Finally, we assert that, during a time of technical change from a labor-intensive to a labor-saving technology, skilled and unskilled labor will appear as substitutes as firms change the ratios they employ of these inputs.

2.1 Historical Background and Implementation of the Policies

2.1.1 School Construction and the Compulsory Education Policy

By the middle of the 1950's, it became evident in Taiwan that the structure of Taiwan's educational system, in which a very high proportion of school-age children attended primary school, but far fewer went beyond that, was in need of reform. For example, for the cohort born in 1944, 88.4% of these Taiwanese completed primary school, but only 34.7% went on to complete any higher level (*Labor Force Survey 1979-1998*). Though opportunities for attending lower secondary school were relatively few at the time, the demand for such education had accelerated to the point where the stresses imposed on children by the selection mechanism for advancement – a competitive entrance examination system, in which only students with the highest scores had the opportunity to continue past primary school – had begun to reach an extreme level. To have a chance at one of the coveted places in lower secondary meant, at the very least, long hours of private supplementary classes in addition to attendance at public school, and even longer hours of extra study.

In the face of such strong demand by parents for more education for their children, the Taiwanese Ministry of Education responded by constructing large numbers of lower secondary schools with the overarching goal of removing the examination requirement. This would be so that there would be a place provided in the local lower secondary school for all students who wished to attend. Though the Ministry of Education had hoped to construct enough schools by 1955, and kept up its school construction project until well past then, by 1965 the widely-criticized examination system for lower secondary places still persisted. At the same time, membership requirements of the International Labor Organization forbade the use of workers under the age of fourteen, so what to do with the island's children aged twelve through fourteen had become a growing social problem. In this climate, the Taiwanese government under Chiang Kai-shek ordered the Ministry of Education to continue its school-building project with the goal of implementing nine years of compulsory education by 1970. This date was later revised to two years earlier, and the extension of compulsory education from six to nine years became law in 1968.

2.1.2 Contemporary Industrial Policy

With the compulsory education policy as a backdrop, it is also important to understand changes taking place with regard to Taiwan's industrialization over the 1980's and 1990's.

Prior to 1979, Taiwan's industrial strategy was primarily export-oriented, seeking to capitalize on its highly educated, yet extremely inexpensive, labor force. Competition between Japan and the United States, particularly in the areas of textiles, plastics, and electronics, forced American manufacturers to look overseas for ways to cut costs, particularly for skilled labor, which domestically was prohibitively expensive. At the same time, Japan's Ministry of International Trade and Investment was also encouraging industries to invest abroad, particularly those industries that were more labor-intensive or technologically simple, so that the domestic industries that remained could concentrate on more high quality, more capital- and knowledge-intensive goods. This led Taiwan to position itself in order to catch these streams of foreign investment, and tailor its industrial base accordingly (Gold 1986).

By the mid-1970's, however, this strategy was beginning to falter. Overseas, Taiwan's exports were running into protectionism, especially in the United States; other newly industrializing countries were beginning to compete in providing the same exports; and local wages had begun to rise. Politically, Taiwan lost diplomatic recognition from Japan and the United Nations, which unnerved foreign investment further, prompting capital flight and emigration of skilled personnel to the United States (Wade 1990).

In this environment, the Taiwanese government in 1979 launched a Science and Technology Development Program in order to shift the focus of Taiwan's industrial development from heavy, capital-intensive industries to non-energy intensive, non-polluting and technology-intensive industries. In order to provide the infrastructure for this development, the government instituted and funded research and development institutes in strategic parts of Taiwan and provided a number of incentives for the development of high-tech industries (Hoesel 1999). In particular, this meant the establishment of the Hsinchu Science-Based Industry Park, which was designed to allow both domestic and foreign high-technology firms to operate in close proximity to the laboratories of the Industrial Technology Research Institute (ITRI), a government institution with responsibilities to conduct key core industrial research, disseminate research findings to the private sector and assist small and medium-sized firms in improving their production processes or upgrading their

technology.¹ The measures also included increased protections for intellectual property. The government hoped that, by establishing ITRI and encouraging cooperation between foreign multinational corporations and domestic firms, it could expedite the transfer of technology from the former to the latter and actively promote industrial automation, moving away from more labor-intensive production technologies (Li 1982). In 1983, the Taiwanese government supplemented the Science and Technology Development Program with a Program for Strengthening the Education, Training and Recruitment of High-Level Science and Technology Personnel in order to attend to the staffing needs of these initiatives and attract overseas talent to lead them (Li 1986).

2.2 Outcomes of the Policies

2.2.1 Outcomes of the Education Policy

Effects on Educational Attainment The Taiwanese education policy had dramatic effects on the educational composition of Taiwan's population, and subsequently on Taiwan's labor force. The most direct indication of the policy's effects is a dramatic increase in the proportion of primary school students advancing to a place in lower secondary school over time, as the following table indicates (*Education Statistical Indicators, Republic of China* 1999):

¹Initially, the primary industries to be promoted consisted of machinery (specifically automotive machinery), electronics, and some chemical industries (Wu 1985). Later, more were added, and by 1990 there were ten: telecommunications, information (mostly computer-aided design and manufacturing), semiconductors, consumer electronics, precision machinery automation, aerospace, advanced materials, specialty chemicals, pharmaceuticals, health care, and pollution prevention. The government also identified eight core technologies: optoelectronics, software, industrial automation, materials application, advanced sensors, biotechnology, resource development and energy conservation (Li 1995).

School Year % Primary Students Promoted to Lower Secondary

1950	31.78
1956	47.75
1961	53.79
1966	59.04
1971*	80.85
1976	90.41
1981	96.77
1986	99.04
1991	99.28
1996	98.89

* first measured year under the compulsory education policy

We note that though there is a substantial spike in promotion levels immediately after implementation of compulsory education, enrollment in lower secondary schools did not truly become universal in Taiwan until about 1986.

The effects of this policy on the educational composition of Taiwan's population become immediately apparent when we observe the proportions of people in Taiwan with the required level of compulsory education (lower secondary) or more by year of birth. Figure 1 shows these proportions for all of Taiwan. Labor force surveys taken from 1979 to 1998 allow us to observe the educational attainment of cohorts born from 1879 through those born in 1983. The vertical line on the right is drawn for the year 1956, the year of birth for the first cohort to be affected by the compulsory education law. Students turning 12 in 1968 would have graduated from primary school that year and then been the first compelled to attend lower secondary under the new regulation. The vertical line on the left is drawn for 1938; students turning 12 in 1950 were the first to benefit from the Ministry of Education's continuing school construction plan. The rising trend in educational attainment before then we attribute to policies of Japanization undertaken during Japan's colonial rule of the island from 1895 to 1945; it had been the view of the Japanese colonial government that

using the educational system to improve literacy and promote cultural assimilation would be the best strategy for the colony's long-term stability and economic success. The dip in educational attainment immediately to the left of the 1938 line we attribute to chaos caused by World War II and the Nationalists' closing of Japanese schools and repatriating Japanese teachers upon taking power in 1945. Additionally, many less-educated immigrants from the mainland, who arrived with the Nationalist army, were from these birth cohorts. We immediately observe that, in Taiwan as a whole, the date of beginning the school construction policy seems to be more important than the date of the compulsory education law in terms of the shift in Taiwan's educational attainment. That said, the Ministry of Education had been ordered to continue its school construction policy for the express purpose of preparing for the implementation of the compulsory education law, so the absence of a sharp jump in educational attainment at the point of the law's passage should not be taken as evidence that the law's effect was only marginal given that the school construction policy was already underway.

What is particularly interesting about the policy is that examination of these proportions by county show that the policy had strikingly different effects in different parts of Taiwan. For example, Figure 2 shows the proportions of people with the nine years of compulsory education by year of birth only for those living in Taipei, Taiwan's capital and largest city. More than half of all men and a quarter of all women in Taipei received at least nine years of education well before the compulsory education policy was implemented. By contrast, we find that the proportions of those receiving nine years or more of education but living in Taipei Hsien (the county that constitutes the rural area surrounding the capital), shown in Figure 3, are substantially less for the years preceding the compulsory education policy. In Yunlin Hsien, an even more remote part of Taiwan, the contrast is even starker (Figure 4). Therefore, an interesting feature of the policy is that its effects were markedly more pronounced in the more rural areas of Taiwan than they were in Taiwan's more urban areas. Many students in Taipei City and other more urban areas were already receiving nine years of education or more, and the compulsory education policy in these places had relatively little effect.

Effects on the Relative Supply of Labor Table 1 summarizes changes in the composition of Taiwan's labor force between a number of different demographic groups both over time and by birth cohort. The

quantities given are the percentage each group represents of the total number of people in the labor force. Immediately we observe a number of trends; in addition to Taiwan steadily acquiring a more gender-balanced labor force, we observe that that labor force has also grown more highly-educated. Taiwan's labor force also became more aged over this time period, with the median worker age rising from 32 years in 1979 to 37 years in 1998 (*Labor Force Survey 1979-1998*).

The relative contribution of those workers with only a primary education declines sharply over time, accounting for 43% of the total labor force in 1979 but only 19% of the labor force in 1998. This is to be expected, since most entrants to the labor force over this time period were young people completing their schooling and most of those exiting were older retirees, and the former group was affected by the compulsory education policy while the latter group was not. But most of the new workers entering the labor force did not stop at merely the level of education they were required to attain. Though the proportion of lower secondary workers entering the labor force increased in successive birth cohorts through 1961, this trend reversed itself by the time the 1965 birth cohort was born, with most of these workers opting either for vocational training (representing at least 12 years of education) or a university degree. As a result, the proportions of workers in the labor force from higher educational groups all posted strong increases over time, with the proportion of workers graduating from vocational and technical colleges increasing the most swiftly from 1979 to 1989. From 1994 to 1998, however, the proportion of workers with university degrees and higher qualifications was the one that grew the most rapidly.

2.2.2 Outcomes of the Science and Technology Development Program

The favorable environment created by the Science and Technology Development Program had a substantial impact on production in Taiwan, particularly with respect to the manufacturing sector. The most wide-ranging evidence for technological change in production comes from examining the capital-labor ratio in Taiwanese industries over time. In the manufacturing sector, fixed assets per employee in Taiwan for Taiwanese firms more than doubled from US\$7,150 in 1976 to US\$14,610 in 1986. For foreign firms, fixed assets per employee more than tripled over the same time period, from US\$6,490 in 1976 to US\$19,680 in 1986 (Schive and Tu 1991). These figures indicate substantially different roles in Taiwan for foreign firms

in 1976 and 1986. In 1976, the principal attraction of producing something in Taiwan for foreign corporations was inexpensive semiskilled labor, and so foreign firms tended to take advantage of this and used more labor-intensive methods than did domestic firms. In 1986, however, the principal attraction became tax incentives and even government-provided venture capital for firms willing to relocate high-technology production facilities to Taiwan and share these methods with the Taiwanese (Li 1995). Therefore it is not surprising that the character of manufacturing production, with the government's new emphasis on high technology and industrial automation, changed dramatically over this time period.

Anecdotal evidence from more specific industry studies also indicates a substantial change in the character of production in Taiwan after the implementation of the Science and Technology Development Program. For example, Gereffi and Pan (1994) note that in the garment industry, Taiwanese apparel firms shifted from largely manufacturing the garments themselves to providing raw materials and machinery to garment factories in places like Indonesia or China, where labor was much less expensive. Some made efforts to build a brand name and move into retailing, but expansions of this type even further skewed the ratio of skilled workers to unskilled workers needed. For the information technology industry, Li (1995) observes that the Taiwanese government succeeded in luring many overseas Chinese researchers and engineers back to Taiwan to form joint ventures with local firms in the Hsinchu Science-Based Industrial Park; from 1981 to 1991, the number of researchers in science and technology doubled to 23 per 10,000 people, which is close to the level seen in fully developed countries. Wu and Tseng (1997) characterize these people as being extremely important to the technology transfer process. In the 1960's and 1970's, Taiwan's brightest college graduates would often seek either advanced degrees overseas or to work for a foreign subsidiary, attracted by better working conditions and higher pay. In the 1980's, many of these returned to high-ranking positions in Taiwanese firms, bringing their acquired knowledge of production methods with them.

2.2.3 Implications of the Science and Technology Development Program for Technology-Skill Complementarity

Importantly, we believe that this industrialization set the stage for a transition to higher technology-skill complementarity in the way described by Goldin and Katz (1996). Goldin and Katz identify the commonly-

observed complementarity of skilled labor with capital not simply as an innate quality of capital itself, but instead as the result of adoption of production processes that create that complementarity. Specifically, they identify the diffusion of batch and continuous-process production methods as the source of the capital-skill complementarity that emerged in the United States between 1910 and 1940. In their model, they see manufacturing as being composed of two, distinct stages; a capital maintenance stage in which machinery is installed and maintained, and a production stage in which the machinery is used to produce something. The first stage always requires highly skilled technicians to install the capital and get it running. Provided that everything is running smoothly, however, unskilled labor is sufficient for the second stage. One imagines the skilled and unskilled working together as complements in this process. But if we introduce technological change – say, a new machine that is more complex to run but substitutes for large numbers of unskilled laborers – the relationship changes. More skilled workers are needed to keep the machine running, but fewer unskilled workers are needed to run it, so the former effectively substitute for the latter until a new ratio of skilled to unskilled workers, appropriate to the new technology, is reached. This is different from the conclusion of previous studies (Chiswick 1985, Hamermesh and Grant 1979), which have argued that capital and unskilled labor are substitutes. We say that they are complements but observed as substitutes during a time of technical change.

The Taiwanese case is a natural application of this framework. Since we know that the 1980's were a time of substantial technical change in Taiwanese manufacturing, specifically promoting industrial automation and other labor-saving measures, we would expect to see substitutability between skilled and unskilled labor during the period of time in which the new technologies are adopted. After this transition, and after employment has stabilized at a new inherent ratio of skilled to unskilled labor, we would expect to see complementarity between these types of labor.

2.3 Summary and Conclusion

In summary, the results in this section reveal profound and rapid changes in the educational attainment of Taiwan's population across birth cohorts. While only a third of students born in 1944 went on to any education past primary school, by the cohort born twenty years later, three years of secondary education

had become universal and almost three quarters of students exceeded this mark. Accordingly, the supply of educated graduates, particularly young educated graduates, in Taiwan's labor force increased rapidly from 1979 through 1998. At the same time, the character of production in Taiwan's manufacturing sector shifted from labor-intensive to higher technology labor-saving processes, creating the potential for skilled workers to substitute for unskilled workers as firms upgraded their production methods. In the next section, we will describe the changes in the wage changes these groups of workers experienced over this time and see how much we can explain in terms of shifts in relative labor supply. Then, in section 4, we will measure the complementarity among these different types of workers over this time and explain the remaining variations in wages as the result of the adoption of a new production technology in the 1980's.

3 Changes in Taiwan's Wage Structure

3.1 Methodology

3.1.1 Data

The data we make use of to measure changes in the wage structure are from the May supplements of Taiwan's monthly Labor Force Survey, which has been administered by Taiwan's Directorate-General of Budgeting, Accounting and Statistics every year since 1979. The survey is in the form of a household survey and asks detailed questions on wages earned, hours worked, and job held in addition to demographic information such as highest level of education attained and place of residence. The survey is limited to those aged fifteen and higher. Every year, the survey is given to approximately 19,000 households, which at an average household size of slightly more than 3 members over 15 years of age translates into approximately 60,000 observed people each year, of whom about half participate in the labor force. In all, the data sets from 1979 to 1998 comprise a substantial merged dataset with 1,144,471 individuals observed in total.

3.1.2 Measuring Variations by Cohort and in Time

At first blush, one might try to measure the changing return to education in Taiwan by estimating a standard wage equation with the form

$$W_i = \beta_0 * gender + \beta_1 * age + \beta_2 * age^2 + \beta_3 * Y_{ei} + \epsilon_i$$

where W_i represents the individual's log hourly wage, and Y_{ei} is a vector of education indicators interacted with a complete set of year indicators. ϵ_i is a normally, independently distributed error term with mean zero and standard deviation σ . This would allow us to compare the relative wages between different types of educated labor from year to year by simply comparing the estimated coefficients within β_3 . However, this assumes that, after allowing for some difference in productivity due to varying years of experience, workers are perfectly substitutable across birth cohorts. Since we think like-educated workers of different birth cohorts are unlikely to be in competition for the same positions over their shared time in the labor force, we instead adopt this specification:

$$W_i = \beta_0 * gender + \beta_1 * age + \beta_2 * age^2 + \beta_3 * Y_{ei} + \beta_4 * B_{ei} + \epsilon_i \tag{1}$$

where the additional term B_{ei} is a vector that interacts education states with the birth cohort of the individual. This allows us to think of the wage for individuals with a certain educational level as being made up of two components: a fixed component that they carry throughout life along with other members of their birth cohort who have obtained this level of education, and a variable component they share with everyone of that educational level but which changes over time.

3.2 Empirical Results

3.2.1 Cohort Effects

Figures 5 through 16 show our estimation of the varying returns to education across birth cohorts, along with the changes in the proportion of each cohort in the labor force with a certain educational level. The

wage levels shown are our parameter estimates of β_4 in equation 1 above. These can be thought of as cohort-education fixed effects. The proportions are shown for each cohort when that cohort is between 30 and 50 years of age, inclusive, which is the period of highest labor force participation for men and women in Taiwan. We selected this age range because we did not want the proportions to be distorted by differing times of individuals' entering into the labor force or retiring from it, both of which we would expect to be systematically related to the ultimate level of education attained.

The striking finding is that, even after controlling for age, there are large, significant differences in the returns to different educational qualifications across birth cohorts. For example, for men, in Figure 5, we see that the return to a primary education for someone born in 1961, a cohort in which less than 10% of its members stopped school at the primary level, is almost 30% higher than the return for someone born on 1933, a cohort in which almost 60% stopped at the primary level. Similarly, in Figure 8, we see that someone who attained a vocational college degree born in 1933, a cohort in which less than 3% attained such degrees, typically earned almost 30% more than someone born in 1961, to a cohort in which more than 10% attained such degrees. For women, we see similar trends; looking at Figure 11, the return to a primary education for a woman born in 1961 is more than 30% higher than that for a woman born in 1933, but looking at Figure 13 we see that the return to a vocational college education for a woman born in 1961 is more than 40% lower. We view this as strong evidence for the cohort effects argued to exist by Clark and Hsieh (2000). These findings are particularly significant in the light that they represent a difference in earnings workers will carry with themselves throughout their time in the labor force, directly impacting total lifetime income. The only returns that do not change very much across birth cohorts are those to a lower secondary education.

3.2.2 Year Effects

Figures 17 through 26 show our estimation of the varying returns to education across years. In order to filter out inflation, the wage levels shown are wages relative to someone with a lower secondary education. We start in 1979 with the relative wages for each educational level observed for the 1945 cohort, and then continue from there with our parameter estimates for β_3 . We could have started with a different cohort, or

zero for that matter, but this would only have affected the level of the wage curves and not their shape.

For most of the educational groups, we find that the relative returns to education decrease as education becomes less scarce, though not with effects as dramatic in magnitude as those we observed across birth cohorts. Likely this would be because the aggregate educational composition of Taiwan's labor force, being a moving average of the educational composition of successive birth cohorts, changed much less dramatically from year to year than did that of the birth cohorts themselves. For example, for men, Figure 18 indicates that the relative return to an upper secondary qualification dropped by about 6% from the early 80's through the 90's, while the proportion of those in the labor force with such a qualification rose from about 8% to near 10%. Figure 19 tells a similar story, with the relative return to a senior vocational qualification dropping by about 7% as the proportion of those with such a qualification in the labor force rises from 10% to close to 25%. Figures 20 and 21, however, show that the returns to vocational college or a university education remained about the same or even increased slightly over the time period, despite increases in relative supply; and Figure 17 shows a precipitous drop in the return to a primary education over the same time period, even as the number of people with a primary education in the labor force declines sharply. Finally, for women, excepting primary education, Figures 22 through 26 show consistent increases in the return to education over time, despite increasing proportions of educated women in the labor force. We speculate that this is because of more women choosing to work full-time, in positions that they had perhaps not traditionally occupied.

3.3 Summary and Conclusion

We have shown that, when measured across birth cohorts, there are large declines in the wage premium to education associated with being born to a better-educated cohort. When measured across time, however, we find a large, unexplained drop in the return to a primary education, even though the proportion of people with this level of education in the labor force declined rapidly. In the next section, we present empirical evidence showing that these workers were acting as substitutes for skilled workers during the time of technical change in Taiwan's manufacturing sector, explaining this trend in terms of a transition to technology-skill complementarity like that described by Goldin and Katz (1996) for the United States in the early twentieth

century.

4 Changes in Factor Complementarity Among Different Types of Educated Labor

In this section, we present a theoretical framework for estimating the elasticities of complementarity among different types of educated labor in Taiwan. Then, we interpret the results of this estimation and show why the results are consistent with a change in the character of production in Taiwan under the government's science and technology development policy.

4.1 Theoretical Framework

To estimate elasticities of complementarity among different types of educated labor in Taiwan, we will first need to make assumptions about labor markets and how workers are compensated, and then specify a production function. Then we will use the parameter estimates of our production function to construct Hicks elasticities of complementarity between different classes of labor. The advantage of this method over simply measuring an empirical elasticity of substitution without an explicit production function is that it allows us to test the separability assumptions such models often rely on, and also it lets us test whether or not there is any evidence for these parameters have changed over time.

Our assumptions about labor markets in Taiwan are the following: that labor of different types is exogenously dropped into the economy, that labor markets clear, that prices are perfectly flexible, and that wages are paid to labor according to its marginal product. We select a translog production function as our operating production function. The advantages of this function are that it is quite flexible and also its parameters readily lend themselves to calculating elasticities of complementarity.

4.1.1 Estimation of a Translog Production Function

The translog production function, first introduced by Christensen, Jorgenson and Lau (1973), usually takes the form

$$\ln(F) = \ln(\alpha_0) + \sum_i \alpha_i \ln(L_i) + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln(L_i) \ln(L_j)$$

where the L 's represent factors of production. In what follows, these will represent different types of labor, but for now we can think of them as being any factor of production we like. Differentiating both sides of the production function with respect to $\ln(L_i)$ yields a system of linear equations relating the translog parameters to the cost share of each factor²:

$$S_i = \alpha_i + \frac{1}{2} \sum_j \gamma_{ij} \ln(L_j)$$

We use Zellner's seemingly unrelated regression method to solve for the parameters, subject to the identification restriction $\gamma_{ij} = \gamma_{ji}$. Other constraints that could be imposed are homotheticity ($\sum_j \gamma_{ij} = 0 \forall i$) and constant returns to scale (homotheticity and $\sum_i \alpha_i = 1$), but these hypotheses are decidedly rejected by our data, so we do not do so. We initially consider five factors of production, one of which is capital stock and the other four are types of labor. Following Hamermesh and Grant (1979), the four labor types result from dividing workers into skilled workers and unskilled workers (the definition of "skilled" being completion of a lower secondary education or higher) and then subdividing those groups into young and old ("young" being defined as being born in 1953 or later, the first generation to substantially benefit from the school construction policy).

4.1.2 Separability of Labor Inputs of Interest

Since we are primarily interested in labor inputs, and our measure of rents paid to Taiwan's capital stock, from the national income accounting statistics, is much less accurate than our measure of wages paid to labor, from the labor force surveys, we would like to know if we can exclude capital from our estimation.

²On the left-hand side, $\frac{\delta \ln(F)}{\delta \ln(L_i)} = \frac{\delta F}{\delta L_i} * \frac{L_i}{F} = \frac{W_i L_i}{F} \equiv S_i$.

Doing so is equivalent to assuming that it is acceptable to rewrite the aggregate production function

$$g(K, L_1, L_2, L_3, L_4)$$

as

$$G(K, f(L_1, L_2, L_3, L_4))$$

wherein the level of capital has no effect on the relative marginal productivities of the different types of labor. Denny and Fuss (1977) show that separability is testable, assuming the translog functional form is a second-order approximation of the true production function, as the hypothesis

$$\alpha_i \gamma_{jk} - \alpha_j \gamma_{ik} = 0$$

where i and j are the inputs included in f and k is excluded. This must be true for any i and j we select from the included inputs and any k we select from the excluded inputs. We will test this hypothesis and then show both sets of results, with capital both included and excluded from the estimation.

4.1.3 Implications of the Translog Parameters for Elasticities of Complementarity

Hicks Elasticity of Complementarity The Hicks elasticity of complementarity between two factors of production i and j is defined to be

$$C_{ij} \equiv \frac{FF_{ij}}{F_i F_j}$$

where the subscripts denote partial derivatives of the production function with respect to that factor. Intuitively, it can be thought of as the proportional change in factor i 's relative wage given a proportional change in the supply of factor j , assuming that the output price and other input quantities remain constant (Hicks 1970).

In the appendix, we show that we can calculate the Hicks elasticities of complementarity in terms of the

translog parameters and the cost shares:

$$C_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}$$

$$C_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2}$$

Empirical Elasticity of Substitution Another measure sometimes seen in the literature is what we will refer to as the empirical elasticity of substitution (c.f. Bowles 1970, Psacharopoulos and Hinchliffe 1972).

This estimation technique is based on the definition of the elasticity of substitution:

$$\sigma_{ij} = -\frac{d \ln \left(\frac{L_i}{L_j} \right)}{d \ln \left(\frac{F_i}{F_j} \right)}$$

Accepting that wages are paid according to the marginal product of labor, this suggests running a regression of the form

$$\ln \left(\frac{W_{it}}{W_{jt}} \right) = \alpha_{ij} + \beta_{ij} \left(\ln \left(\frac{L_{it}}{L_{jt}} \right) \right) + \epsilon_t$$

where a number of observations of relative wages and relative labor supplies are made in time periods indexed by t . One would then estimate σ_{ij} as $-\frac{1}{\beta_{ij}}$. We show in the appendix that the translog parameters and cost shares also imply the empirical elasticities of substitution we should observe. These imply

$$\beta_{ij} = (\gamma_{ii} + S_i^2 - S_i) - \frac{\gamma_{ij} + S_i S_j}{S_i}$$

We can also express this parameter in terms of Hicks elasticities of complementarity:

$$\beta_{ij} = C_{ii} S_i - C_{ij} S_j$$

implying

$$\sigma_{ij} = \frac{1}{C_{ij} S_j - C_{ii} S_i} \tag{2}$$

Empirical Equivalence of Q -Complementarity and P -Substitution Looking at (2), we note that the more positive the Hicks elasticity complementarity between two factors C_{ij} , the more likely the empirical elasticity of substitution σ_{ij} between the same two factors is to be positive. This is not the contradiction it might seem to be; the reason is that the empirical elasticity of substitution is related to the cross elasticity of derived demand when the price of one of the factors changes, but the Hicks elasticity of complementarity is related to the inverse of the same elasticity when the quantity of one of the factors changes, which are dual problems. Sato and Koizumi (1973) refer to such factors as p -substitutes if an increase in the price of one factor is associated with an increase in the price of the second factor, and q -complements if an increase in the quantity employed of one factor is associated with an increase in the quantity employed of the second factor. Empirically, since in both cases we observe a negative correlation between relative supply and relative prices (in the first case, the increase in the price of the first factor leads to an increase in the quantity demanded of the second factor, and in the second case, an increase in the price of the second factor is caused by an increase in the quantity supplied of the first factor), they are indistinguishable.³ However, since in our theoretical framework we are taking quantities supplied of different factors as exogenous, which then determine prices in a free market according to the marginal product of each, it makes more sense to focus on q -complementarity and the Hicks measure.

4.2 Empirical Results

4.2.1 Parameter Estimates & Tests of Parametric Assumptions

Tables 2, 3, and 4 show our estimates of the translog parameters according to the methodology above. Table 2 shows the results when we estimate the parameters using all the years of data we have, both including and excluding capital. Standard errors for the estimates are given in parentheses. Tables 3 and 4 show the same parameters when we allow them to take two different values, one for the decade from 1979-1988 and another for the decade from 1989-1998. We first note that, in all cases, we fail to reject the separability hypothesis ($p = 0.81$ for all years together, $p = 0.89$ for the parameters allowed to take on different values in the two

³Strictly speaking, it is only in the two-factor case that p -substitutes must necessarily be q -complements and vice versa. However, in the multifactor case, the two relationships are still observationally equivalent, that is, a negative correlation between relative supply and relative price alone is not sufficient to rule out either of these cases.

decades), so we are free to focus on the more precise estimates that exclude capital from our calculations.

The estimates of the translog parameters can be thought of as telling us what happens to the marginal productivity of one factor of production when the quantity employed of a second factor of production is increased. In general, a positive coefficient on one of the γ interaction terms implies q -complementarity, and a coefficient less than negative one implies q -substitutability. The complementarity or substitutability implied by a coefficient between negative one and zero depends on the cost shares, which are derived from the other interaction terms and the α terms that also add into the calculation of the cross partial. Between negative one and zero, the γ interaction term will not dominate these other terms. To see this, recall

$$C_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}$$

$S_i S_j$, being two cost shares multiplied together, is bounded by zero and one. C_{ij} is of course always positive if γ_{ij} is positive, and negative if and only if $\gamma_{ij} < -S_i S_j$, $-S_i S_j$ being bounded by zero and negative one. $\gamma_{ij} < -1$ is a sufficient condition for q -substitutability no matter what the cost shares. But if γ_{ij} is between negative one and zero, though it may be suggestive of a substitute relationship, we cannot know for sure without looking at the cost shares.

In Table 2, we note the relationships between young skilled, old skilled and old unskilled workers have a character of being q -substitutes over the time period studied ($\gamma_{yos} = -0.091$ (0.005); $\gamma_{ysou} = -0.103$ (0.006); $\gamma_{osou} = -0.061$ (0.018)). But none of the coefficients are negative enough to definitely classify any of these relationships at this point. Further, no parameter describing a relationship between capital or young unskilled workers and another factor of production is of any significance at the 5% level. In Tables 3 and 4, though we decidedly reject the hypothesis that the parameters are equal across decades, we still do not find many cases of individual parameters differing significantly from one decade to another. One notable exception is γ_{ysou} , which we observe in the calculations excluding capital moving from being -0.110 (0.007) in the first decade to -0.050 (0.012) in the second. The hypothesis that they are the same is rejected at $p < 0.000$. This is suggestive of a decline in substitutability between young skilled and old unskilled workers from one decade to the next. The only other parameter to differ significantly across decades is γ_{ouou} , but the difference is only marginally significant ($p = 0.049$).

4.2.2 Estimated Elasticities of Complementarity

Figures 27 and 28 show the estimated Hicks elasticities of complementarity for two pairs of labor inputs: young skilled and old skilled, and young skilled and old unskilled. We also include 95% confidence intervals, assuming that the cost shares we have measured are nonstochastic. We do not show relationships involving young, unskilled laborers because none of these proved statistically significant. Since the number of people in this group is very small, that we could not find a statistically significant relationship in terms of the complementarity between them and those in other groups is unsurprising. We also do not show the relationship between old skilled and old unskilled workers, as these complementarity estimates also failed to generate a statistically significant result in any year.

In Figures 27 and 28 we observe that the relationship of younger workers to older workers changed markedly from 1979-1998, particularly in the 1980's. In the beginning of the decade, they were largely q -substitutes for both types of older workers, but this changes by the 1990's. By the end of the 1990's, young skilled workers and old skilled workers find that they are now q -complements, and though this is not true for young skilled workers and old unskilled workers, this relationship by the end of the 1990's is still less substitutable than it was before. Intuitively, this means that flooding the market with large numbers of young, skilled workers initially decreased the demand for both old skilled and old unskilled workers, driving down their wages.

For old unskilled workers, this conclusion matches well with what we observed in Figure 17, namely that the relative return to a primary education plummeted throughout the 80's (from a return of about 4% less than that for a lower secondary education in 1979, to about 17% less by 1990), then managed to stabilize somewhat in the 90's. During this time, the reason that the wage premium to a primary education declined at the same time as the relative proportion of primary-educated people in the labor force declined is that younger, more educated entrants to the workforce were substituting for them in large numbers. This is exactly consistent with what we would expect during a time of adopting a more advanced, labor-saving production technology.

For old skilled workers we can tell a similar story; though through about 1986, young skilled workers and old skilled workers had a q -substitute relationship, their relationship became q -complementary after that.

Looking at Figure 18, we can see that much of the relative decline in the return to an upper secondary qualification occurred between 1979 and 1986 (from a premium of about 17% to a premium of about 14%), and looking at Figure 19, we can see that something similar is true for senior vocational qualifications (declining from a premium of 19% to a premium of 15% during the same seven year period). Figure 20 indicates that the relative return to vocational college remained fairly constant over the whole time period, but Figure 21 indicates that the relative return to a university education increased steadily over the same time. This indicates that there are compositional factors at work, and that the q -substitutability result is primarily driven by declines in the wage premium for those with a secondary (either academic upper secondary or vocational upper secondary) qualification but no tertiary qualification. This makes sense, considering that secondary qualifications alone would not have been sufficient to qualify a worker to be employed by the capital maintenance phase under the more advanced technology promoted by the Science and Technology Development Program.

4.2.3 Empirical Elasticities of Substitution for Specific Industries

Though we concentrated on the Hicks measure of complementarity, it is instructive to show the analogous result had we instead estimated the empirical elasticity of substitution. Figure 29 shows the log relative wages of young skilled and old unskilled labor in Taiwan graphed against log relative labor supply. We smooth the data using Fan's locally weighted regressions, choosing a quartic kernel and a bandwidth of 0.6. We also show bootstrapped 95% confidence intervals for the smoothed point estimates. Since the relative supply of young, skilled labor increases monotonically with time, moving from left to right on the graph also implies moving forward in time. The vertical line is drawn for the year 1987. Empirically, were we to measure the slope of this curve, we would find an estimate of β_{ij} that is positive for the pre-1987 period (indicating p -complementarity, or q -substitutability) and negative for the post-1987 period (indicating p -substitutability, or q -complementarity). This matches our findings with the Hicks measure.

The advantage in doing this is that it is simple to disaggregate the empirical elasticity of substitution by industry, and thereby test our assertion that the source of this trend from q -substitutability to q -complementarity is caused by skill-biased technical change. If this is the case, the trend should be more

pronounced within industries that significantly changed their production methods and less pronounced within industries that did not. This of course presumes that there are frictions that prevent workers from easily switching between industries in response to negative wage shocks. Pack and Paxson (1999) find, for Taiwan, that workers are more likely to move from one industry to another if the industries share a number of the same inputs, but tend to move less, and gain less, from moving to industries in which they are presumably less familiar (i.e., do not share many of the same inputs). For our industries, we compare manufacturing, social and personal services, and agriculture, three sectors between which we expect inter-industry labor mobility to be quite low. These are indicated by Figures 30, 31, and 32, respectively. All of these figures use the same scale for their axes, so they are directly comparable.

Looking at Figures 30 and 31, we see that the shift from q -substitutability to q -complementarity for young skilled and old unskilled labor is indeed much more pronounced for manufacturing than it is for either social and personal services or agriculture. This tells us that shift was driven primarily by changes within manufacturing and related sectors. Since much of the Science and Technology Development Program was focused at the manufacturing sector, and we would have expected it to have little impact on social and personal services (which are difficult, if not impossible to automate), this result makes sense. Figure 32, which shows the agricultural industry – also largely unaffected by the Science and Technology Development Program – reinforces this conclusion. Therefore we can assert that this shift was, in fact, caused by a change in the character of production for the manufacturing and related sectors.

5 Conclusion

In conclusion, we find that we are able to explain changes in Taiwan's wage structure from 1979 through 1998 in terms of both general equilibrium labor supply effects and a change in the character of production in Taiwan's manufacturing sector. In the wake of the school construction policy, the large increase in the supply of educated graduates depressed the returns to education, particularly for later birth cohorts. Imperfect substitutability between older and younger graduates, however, preserved the high returns to education for those who were fortunate enough to receive that education in an earlier birth cohort.

Secondly, we find that the complementarity between young skilled and old skilled and unskilled workers

changes over time with the adoption of more advanced production technology in the manufacturing sector. More need of skilled labor in the capital maintenance phase of production and less need of unskilled labor in the production phase increased the relative wages paid to the former over the latter and caused skilled and unskilled labor to appear as empirical substitutes during the implementation phase of the new technology.

Studies that seek to measure the substitutability or complementarity of factors, especially within developing countries, should not do so without thinking carefully of the underlying structure of production. In a time of technical change, retooling and moving from one type of production to another can cause factors to appear to be substitutes when they are, in fact, not. This process is often abstracted from – the transition from a state with a high unskilled-to-skilled labor ratio and low capital to a state with a lower unskilled-to-skilled labor ratio and more capital is often thought of as simply substituting capital for unskilled labor. But in a development context, a substantial amount of government intervention may be required to “pick” a more advanced production technology. Therefore, an industrial development policy can be significant in determining whether increasing the supply of skilled labor drives the wages of the unskilled up (if they are complements in production) or down (when moving to a new production technology).

References

- Bowles, Samuel**, “Aggregation of Labor Inputs in the Economics of Growth and Planning: Experiments with a Two-Level CES Function,” *The Journal of Political Economy*, Jan. - Feb. 1970, 78 (1), 68–81.
- Chiswick, Carmel U.**, “The Elasticity of Substitution Revisited : The Effects of Secular Changes in Labor Force Structure,” *Journal of Labor Economics*, October 1985, 3 (4), 490–507.
- Christensen, Laurits R., Dale W. Jorgenson, and Lawrence J. Lau**, “Transcendental Logarithmic Production Frontiers,” *The Review of Economics and Statistics*, Feb. 1973, 55 (1), 28–45.
- Clark, Diana E. and Chang-Tai Hsieh**, “Schooling and Labor Market Impact of the 1968 Nine-Year Education Program in Taiwan,” 2000. Unpublished paper, University of California at Berkeley, Princeton University.

- Denny, Michael and Melvyn Fuss**, “The Use of Approximation Analysis to Test for Separability and the Existence of Consistent Aggregates,” *The American Economic Review*, Jun. 1977, 67 (3), 404–418.
- Education Statistical Indicators, Republic of China*, Ministry of Education, Taiwan, April 1999.
- Gereffi, Gary and Mei-Lin Pan**, “The Globalization of Taiwan’s Garment Industry,” in Edna Bonacich, Lucie Cheng, Norma Chinchilla, Nora Hamilton, and Paul Ong, eds., *Global Production : The Apparel Industry in the Pacific Rim*, Temple University Press, 1994.
- Gindling, T. H., Marsha Goldfarb, and Chun-Chig Chang**, “Changing Returns to Education in Taiwan : 1978-91,” *World Development*, February 1995, 23 (2), 343–356.
- Gold, Thomas B.**, *State and Society in the Taiwan Miracle*, New York: M. E. Sharpe, Inc., 1986.
- Goldin, Claudia and Lawrence F. Katz**, “The Origins of Technology-Skill Complementarity,” July 1996. National Bureau of Economic Research Working Paper: 5657.
- Hamermesh, Daniel S. and James H. Grant**, “Econometric Studies of Labor-Labor Substitution and Their Implications for Policy,” *Journal of Human Resources*, Fall 1979, 14 (4), 518–42.
- Hicks, John**, “Elasticity of Substitution Again: Substitutes and Complements,” *Oxford Economic Papers*, Nov 1970, 22, 289–296.
- Hoesel, Roger Van**, *New Multinational Enterprises from Korea and Taiwan : Beyond Export-Led Growth*. Routledge Studies in International Business and the World Economy, New York: Routledge, 1999.
- Labor Force Survey*, Taipei: Directorate-General of Budget, Accounting and Statistics, Taiwan 1979-1998.
- Li, Kuo-Ting**, “The Promotion of Industrial Automation,” July 13 1982. An address to the opening session of the 1982 International Workshop on Advanced Automation at Academia Sinica, Taipei.
- , “A Report on the Development of Science and Technology in the Republic of China, 1982-6,” February 1986. Speech delivered at the Third National Conference on Science and Technology, Taipei.
- , *The Evolution of Policy Behind Taiwan’s Development Success*, 2nd ed., Singapore: World Scientific Publishing Co. Pte. Ltd., 1995.

- Pack, Howard and Christina Paxson**, “Inter-Industry Labor Mobility in Taiwan, China,” Washington, DC : World Bank, Development Research Group, Public Economics 1999. Policy Research Working Paper: 2154.
- Psacharopoulos, George**, “Time Trends of the Returns to Education : Cross-National Evidence,” *Economics of Education Review*, 1989, 8 (3), 225–231.
- and **Keith Hinchliffe**, “Further Evidence on the Elasticity of Substitution Among Different Types of Educated Labor,” *The Journal of Political Economy*, Jul. - Aug. 1972, 80 (4), 786–792.
- Sato, Ryoza and Tetsunori Koizumi**, “On the Elasticities of Substitution and Complimentarity,” *Oxford Economic Papers*, Mar 1973, 25, 44–56.
- Schive, Chi and Jenn-Hwa Tu**, “Foreign Firms and Structural Change in Taiwan,” in Eric D. Ramstetter, ed., *Direct Foreign Investment in Asia’s Developing Economies and Structural Change in the Asia-Pacific Region*, Boulder, CO: Westview Press, 1991.
- Wade, Robert**, *Governing the Market : Economic Theory and the Role of Government in East Asian Industrialization*, Princeton, N.J.: Princeton University Press, 1990.
- Wu, Rong-I and Ming-Sheng Tseng**, “The Development of the Information Industry in Taiwan,” 1997. International Development Research Institute Occasional Paper No. 7.
- Wu, Yuan-Li**, *Becoming an Industrialized Nation : ROC’s Development on Taiwan*, New York: The Contemporary U.S.-Asia Research Institute, Inc., 1985.

A Mathematical Appendix

A.1 Derivation of the Hicks Elasticity of Complementarity in Terms of the Translog Parameters and Cost Shares

Starting from the cost share equations

$$S_i = F_i * L_i / F = \alpha_i + \frac{1}{2} \sum_j \gamma_{ij} \ln(L_j) \quad (3)$$

rearranging terms implies

$$F_i = \left(\alpha_i + \frac{1}{2} \sum_j \gamma_{ij} \ln(L_j) \right) * \frac{F}{L_i}$$

which tells us

$$F_i F_j = \frac{F^2}{L_i L_j} * \left(\alpha_i + \frac{1}{2} \sum_j \gamma_{ij} \ln(L_j) \right) * \left(\alpha_j + \frac{1}{2} \sum_i \gamma_{ji} \ln(L_i) \right)$$

and

$$F_{ij} = \gamma_{ij} \left(\frac{1}{L_j} \right) * \frac{F}{L_i} + \left(\alpha_i + \frac{1}{2} \sum_j \gamma_{ij} \ln(L_j) \right) * \left(\alpha_j + \frac{1}{2} \sum_i \gamma_{ji} \ln(L_i) \right) * \frac{F}{L_j} * \left(\frac{1}{L_i} \right)$$

Therefore,

$$\begin{aligned} C_{ij} &\equiv \frac{F F_{ij}}{F_i F_j} \\ &= \frac{F^2}{L_i L_j} * \frac{\gamma_{ij} + \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right) * \left(\alpha_j + \sum_i \gamma_{ji} \ln(L_i) \right)}{(F^2 / L_i L_j) * \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right) * \left(\alpha_j + \sum_i \gamma_{ji} \ln(L_i) \right)} \\ &= \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \end{aligned} \quad (4)$$

For C_{ii} , note

$$F_{ii} = \gamma_{ii} \left(\frac{1}{L_i} \right) * \frac{F}{L_i} + \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right) * \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right) * \frac{F}{L_i^2} - \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right) * \frac{F}{L_i^2}$$

Therefore,

$$\begin{aligned} C_{ii} &\equiv \frac{FF_{ii}}{F_i F_i} \\ &= \frac{F^2}{L_i L_i} * \frac{\gamma_{ii} + \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right)^2 - \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right)}{\left(F^2 / L_i L_i \right) * \left(\alpha_i + \sum_j \gamma_{ij} \ln(L_j) \right)^2} \\ &= \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \end{aligned} \tag{5}$$

Further note, since we have assumed that workers are paid a wage equal to their marginal product ($W_i = F_i$), we can express C_{ij} as

$$C_{ij} = \frac{FF_{ij}}{F_i F_j} = \frac{F * \partial W_i / \partial L_j}{W_i W_j} \tag{6}$$

and similarly

$$C_{ii} = \frac{FF_{ij}}{F_i F_j} = \frac{F * \partial W_i / \partial L_i}{W_i^2} \tag{7}$$

A.2 Derivation of the Empirical Elasticity of Substitution in Terms of the Translog Parameters and Cost Shares

Starting from the definition of the empirical elasticity of substitution between two factors i and j ,

$$\begin{aligned} \beta_{ij} &= \frac{d \ln(W_i / W_j)}{d \ln(L_i / L_j)} \\ &= \frac{(dW_i / W_i - dW_j / W_j)}{(dL_i / L_i - dL_j / L_j)} \end{aligned}$$

Since labor supplies are considered to be exogenously determined (we consider the quantities to be fixed

at a given moment in time), $dL_j/dL_i = 0$, allowing us to simplify the above expression for b_{ij} and find:

$$\beta_{ij} = \frac{dW_i}{dL_i} * \frac{L_i}{W_i} - \frac{dW_j}{dL_i} * \frac{L_i}{W_j} \quad (8)$$

To simplify this expression further, we must show

$$\frac{dW_i}{dL_j} = \frac{\delta(W_i)}{\delta(L_j)} \quad (9)$$

is true for all i, j . This also follows from the exogeneity of labor supply. To see why, note that

$$\frac{dW_i}{dL_j} = \sum_{k \in I} \frac{\partial W_i}{\partial L_k} * \frac{dL_k}{dL_j}$$

Because the L 's are fixed, the expression $\frac{dL_k}{dL_j}$ is equal to zero for all $k \neq j$, and of course one otherwise.

Therefore (9) is true. Substituting (9) into (8) and multiplying through by $\frac{FW_i}{FW_i}$, we get

$$\beta_{ij} = F \left(\frac{\partial W_i / \partial L_i}{W_i W_i} \right) \frac{W_i L_i}{F} - F \left(\frac{\partial W_i / \partial L_j}{W_i W_j} \right) \frac{W_j L_j}{F} \quad (10)$$

Then, by substituting (3), (7) and (6) into (10), we can express the empirical coefficient in terms of cost shares and the Hicks elasticity of complementarity:

$$\beta_{ij} = C_{ii} S_i - C_{ij} S_j \quad (11)$$

Finally, by substituting our earlier results (4) and (5) into (11), we can express the implied empirical coefficient β_{ij} in terms of cost shares and the translog parameters:

$$\begin{aligned} \beta_{ij} &= \left[\frac{\gamma_{ii} + S_i^2 - S_i}{S_i} \right] * S_i - \left[\frac{\gamma_{ij} + S_i S_j}{S_i S_j} \right] * S_j \\ \beta_{ij} &= (\gamma_{ii} + S_i^2 - S_i) - \frac{\gamma_{ij} + S_i S_j}{S_i} \end{aligned} \quad (12)$$

Table 1 : Percent Composition of Taiwan's Labor Force, by Year and Birth Cohort⁴
Taiwan Province

Percent of Total, By Year	79	84	89	94	98
Men	67.20%	63.86%	62.40%	61.63%	60.38%
Women	32.80%	36.14%	37.60%	38.37%	39.62%
Total	100.00%	100.00%	100.00%	100.00%	100.00%
Illiterate	7.97%	6.09%	4.11%	2.59%	2.11%
Self-Educated	3.07%	2.36%	1.75%	1.02%	0.49%
Primary	42.96%	36.14%	30.43%	24.55%	18.86%
Lower Secondary	17.96%	19.28%	19.80%	20.68%	19.05%
Upper Secondary	6.58%	7.24%	8.11%	8.90%	9.27%
Senior Vocational	11.69%	16.78%	20.76%	23.53%	25.61%
Vocational/Technical College	4.84%	6.42%	8.33%	10.94%	13.98%
University and Higher	4.92%	5.70%	6.71%	7.80%	10.64%
Total	100.00%	100.00%	100.00%	100.00%	100.00%
Percent of Total, By Birth Cohort	29	33	37	41	45
Illiterate	15.15%	13.72%	13.00%	8.77%	4.04%
Self-Educated	6.08%	5.62%	7.02%	4.11%	1.27%
Primary	52.54%	58.23%	55.39%	53.62%	50.62%
Lower Secondary	10.52%	8.75%	7.97%	10.91%	12.84%
Upper Secondary	4.76%	4.16%	3.51%	4.88%	6.50%
Senior Vocational	4.26%	4.04%	5.94%	8.13%	10.50%
Vocational/Technical College	3.30%	2.74%	3.25%	4.14%	5.93%
University and Higher	3.39%	2.75%	3.92%	5.45%	8.31%
Total	100.00%	100.00%	100.00%	100.00%	100.00%
Percent of Total, By Birth Cohort	49	53	57	61	65
Illiterate	2.25%	0.85%	0.08%	0.00%	0.00%
Self-Educated	0.48%	0.17%	0.01%	0.00%	0.00%
Primary	45.67%	37.05%	18.60%	8.90%	3.40%
Lower Secondary	13.82%	15.04%	25.65%	28.44%	23.59%
Upper Secondary	7.30%	9.07%	9.90%	9.35%	9.97%
Senior Vocational	12.99%	18.72%	24.27%	28.03%	32.07%
Vocational/Technical College	8.63%	10.32%	11.68%	13.83%	17.96%
University and Higher	8.85%	8.78%	9.81%	11.45%	13.02%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

⁴Source: Taiwanese Labor Force Survey (Taipei: Directorate-General of Budget, Accounting and Statistics, Taiwan), various years.



Figure 1:

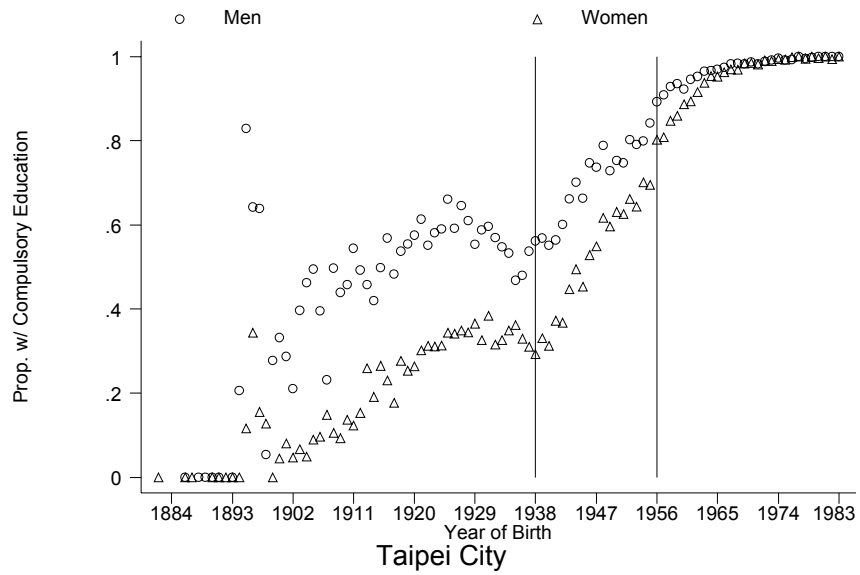


Figure 2:

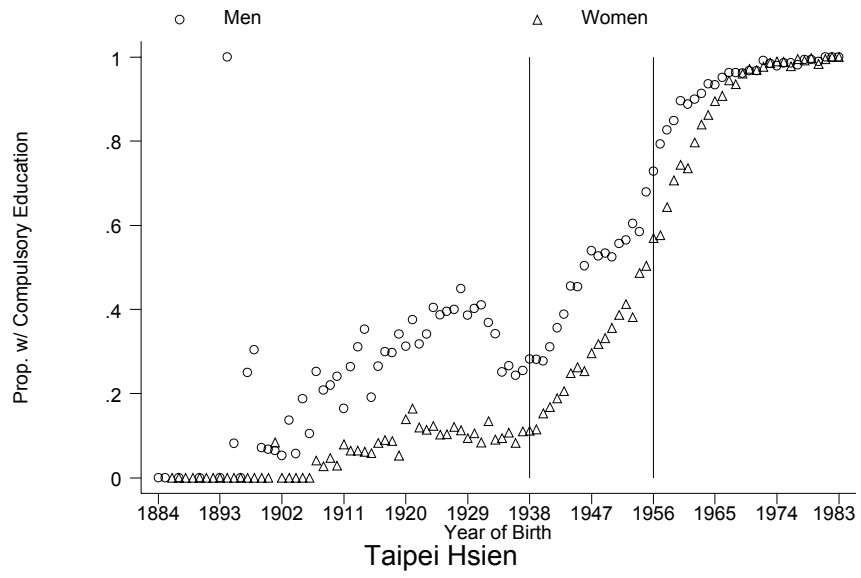


Figure 3:

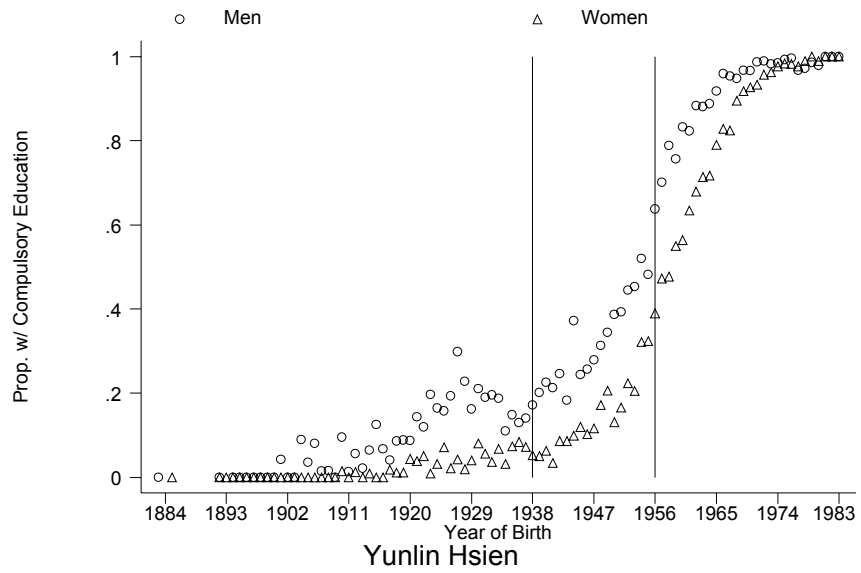


Figure 4:

Table 2: Translog Parameters, All Years⁵

	Capital Included	Capital Excluded
α_{ys}	-0.843 (0.546)	0.394 (0.042)
α_{yu}	0.268 (0.262)	-0.008 (0.090)
α_{os}	0.373 (0.276)	0.232 (0.152)
α_{ou}	0.440 (0.407)	0.569 (0.124)
α_k	1.444 (0.538)	
γ_{ysys}	0.147 (0.033)	0.234 (0.004)
γ_{ysyu}	-0.002 (0.014)	-0.049 (0.006)
γ_{yosos}	-0.016 (0.014)	-0.091 (0.005)
γ_{ysou}	-0.045 (0.021)	-0.103 (0.006)
γ_{ysk}	-0.010 (0.031)	
γ_{yuyu}	0.052 (0.013)	0.116 (0.020)
γ_{yuos}	-0.017 (0.009)	-0.029 (0.013)
γ_{yuou}	-0.023 (0.014)	-0.021 (0.017)
γ_{yuk}	-0.019 (0.014)	
γ_{osos}	0.076 (0.012)	0.185 (0.023)
γ_{osou}	-0.038 (0.012)	-0.061 (0.018)
γ_{osk}	-0.019 (0.014)	
γ_{ouou}	0.080 (0.024)	0.160 (0.020)
γ_{ouk}	0.002 (0.022)	
γ_{kk}	-0.021 (0.030)	

various years.

⁵We fail to reject the separability hypothesis at $\chi^2_{12} = 2.28$ ($p = 0.81$).

Table 3: Translog Parameters by
Decade, Including a Capital Measure⁶

	1979-1988	1989-1998
α_{ys}	0.131 (0.471)	-0.697 (1.503)
α_{yu}	0.451 (0.380)	0.725 (0.926)
α_{os}	0.204 (0.265)	0.509 (0.750)
α_{ou}	-0.521 (0.449)	0.614 (1.135)
α_k	0.414 (0.471)	1.406 (1.603)
γ_{ysys}	0.116 (0.034)	0.263 (0.080)
γ_{ysyu}	0.017 (0.019)	0.003 (0.045)
γ_{yosos}	-0.060 (0.014)	-0.064 (0.037)
γ_{ysou}	-0.067 (0.021)	-0.057 (0.049)
γ_{ysk}	-0.002 (0.034)	-0.077 (0.071)
γ_{yuyu}	0.082 (0.030)	0.026 (0.035)
γ_{yuos}	-0.026 (0.013)	-0.008 (0.023)
γ_{yuou}	-0.042 (0.028)	-0.029 (0.029)
γ_{yuk}	-0.048 (0.020)	-0.033 (0.042)
γ_{osos}	0.096 (0.012)	0.091 (0.028)
γ_{osou}	-0.048 (0.014)	-0.040 (0.025)
γ_{osk}	0.030 (0.014)	-0.003 (0.034)
γ_{ouou}	0.155 (0.034)	0.091 (0.046)
γ_{ouk}	0.039 (0.024)	-0.002 (0.054)
γ_{kk}	-0.014 (0.036)	0.043 (0.076)

⁶We reject the hypothesis that the parameters are equal across decades at $\chi^2_{20} = 60.66$ ($p = 5.6 * 10^{-6}$). We fail to reject the separability hypothesis at $\chi^2_{10} = 5.00$ ($p = 0.89$).

Table 4: Translog Parameters by
Decade, Excluding a Capital Measure⁷

	1979-1988	1989-1998
α_{ys}	0.244 (0.076)	-0.035 (0.304)
α_{yu}	0.142 (0.253)	0.110 (0.211)
α_{os}	0.484 (0.242)	0.701 (0.341)
α_{ou}	-0.340 (0.291)	-0.090 (0.226)
γ_{ysys}	0.237 (0.004)	0.227 (0.016)
γ_{ysyu}	-0.043 (0.009)	-0.049 (0.011)
γ_{yosos}	-0.082 (0.005)	-0.106 (0.016)
γ_{ysou}	-0.110 (0.007)	-0.050 (0.012)
γ_{yuyu}	0.097 (0.030)	0.084 (0.022)
γ_{yuos}	-0.053 (0.014)	-0.015 (0.019)
γ_{yuou}	0.003 (0.022)	-0.014 (0.016)
γ_{osos}	0.205 (0.018)	0.181 (0.037)
γ_{osou}	-0.085 (0.016)	-0.087 (0.024)
γ_{ouou}	0.233 (0.025)	0.170 (0.020)

⁷We reject the hypothesis that the parameters are equal across decades at $\chi^2_{14} = 106.17$ ($p = 3.1 * 10^{-16}$).

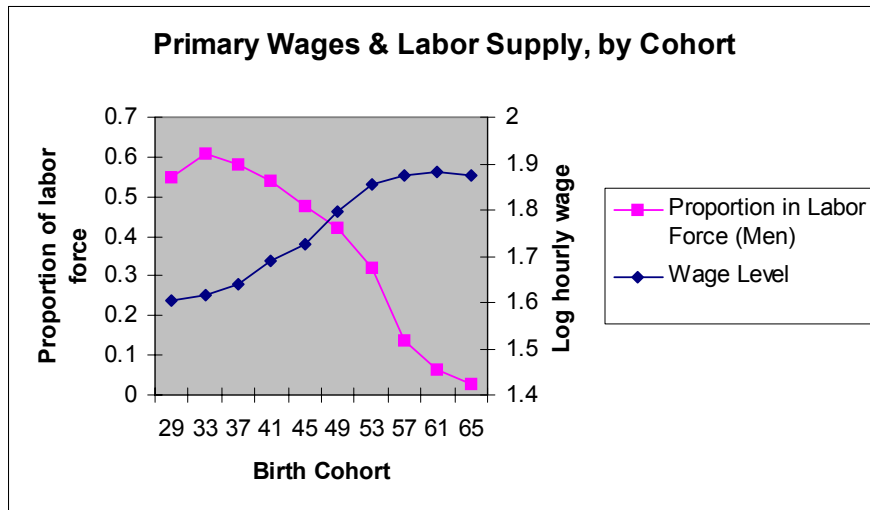


Figure 5:

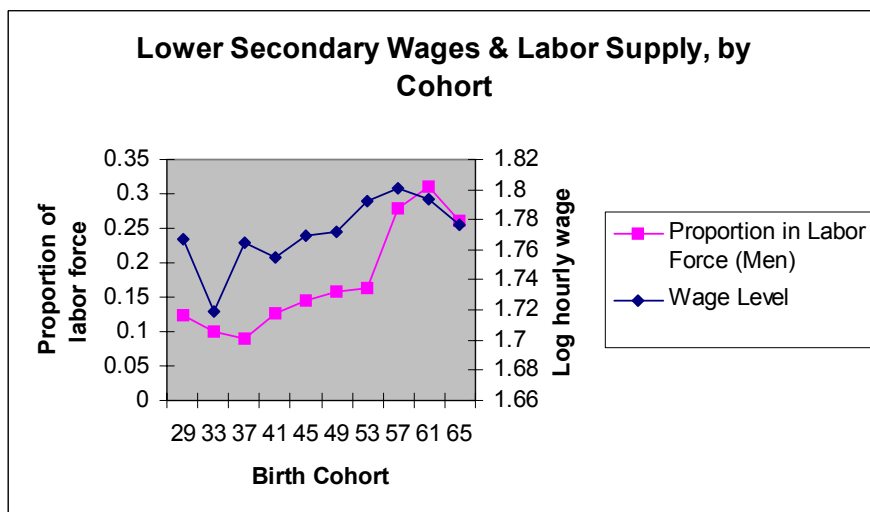


Figure 6:

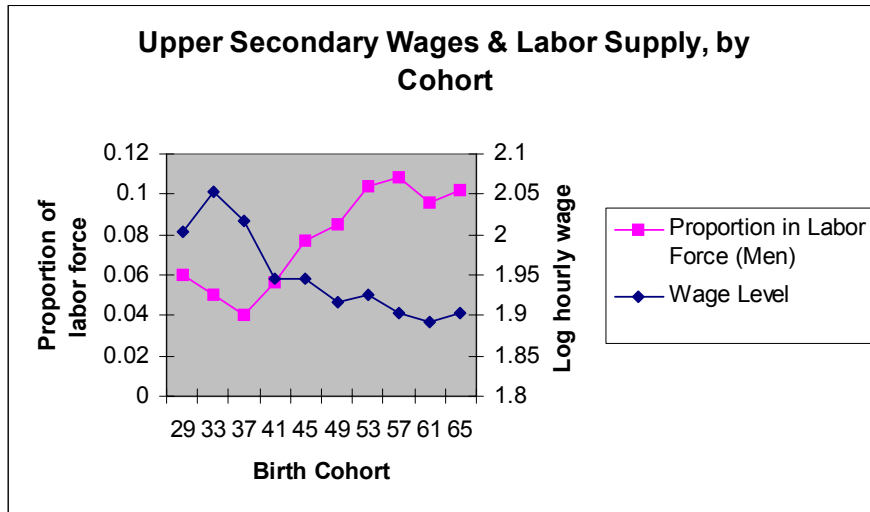


Figure 7:

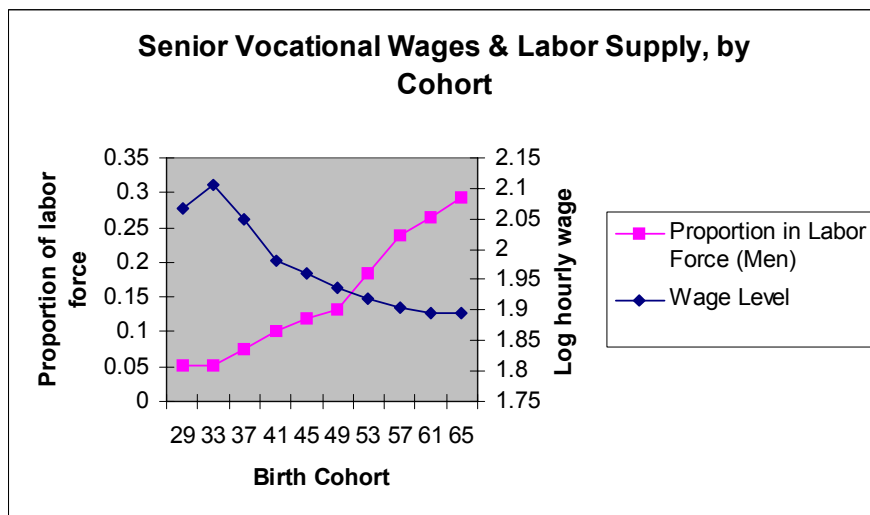


Figure 8:

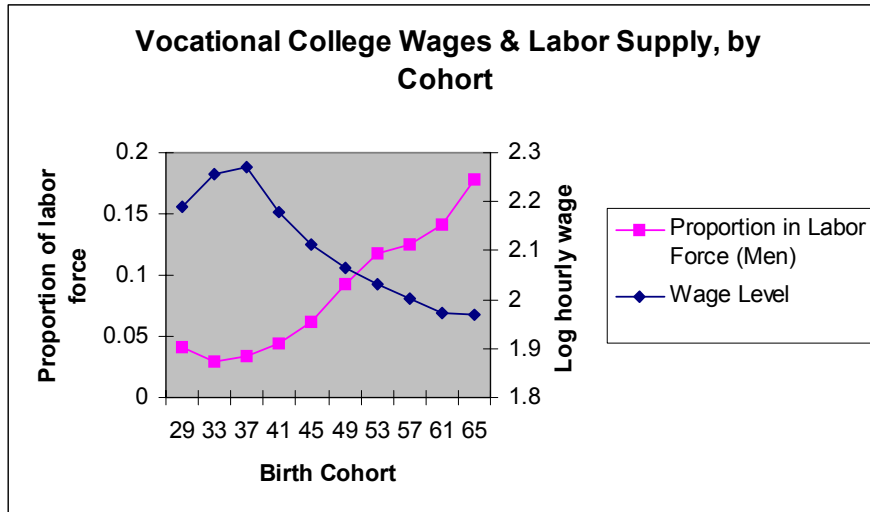


Figure 9:

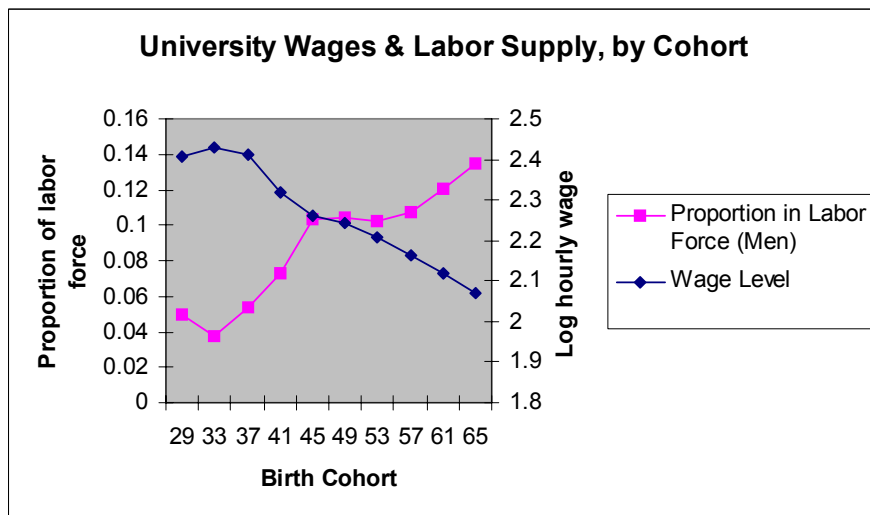


Figure 10:

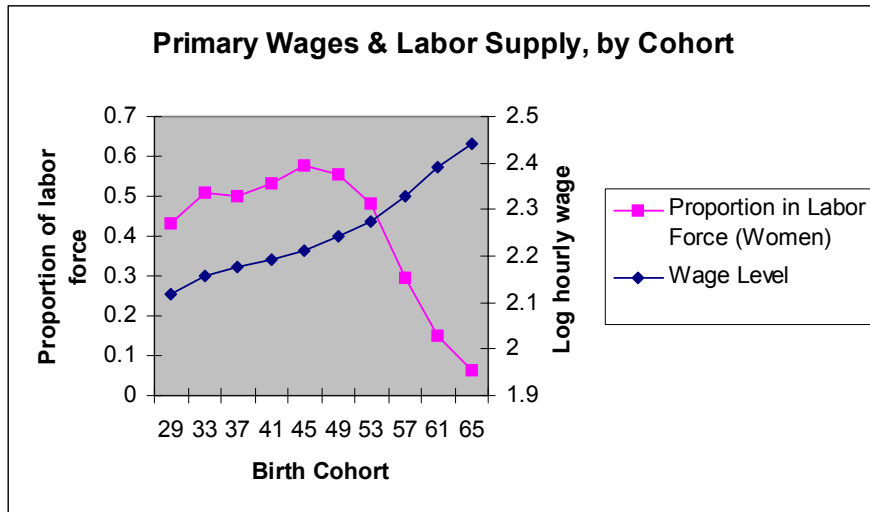


Figure 11:

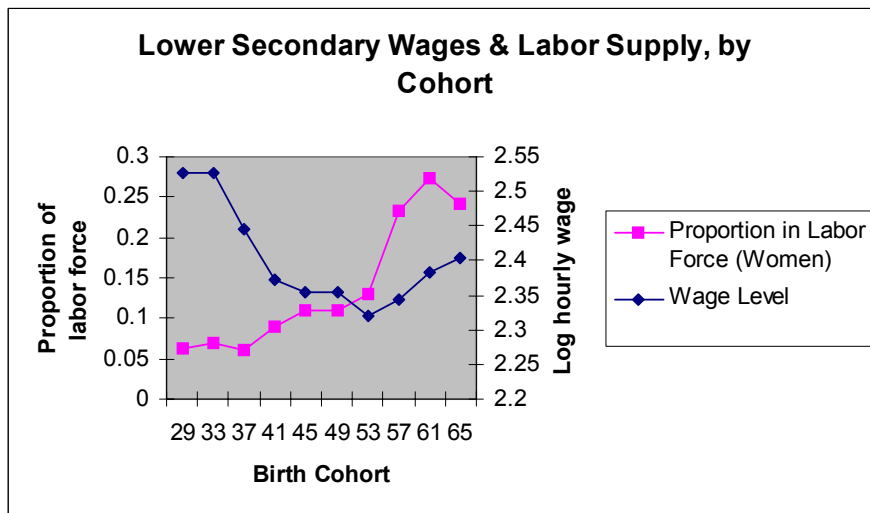


Figure 12:

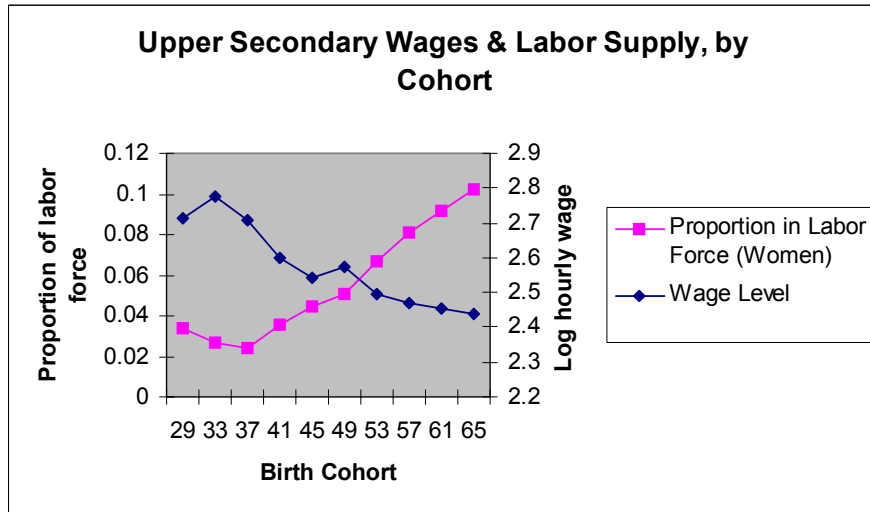


Figure 13:

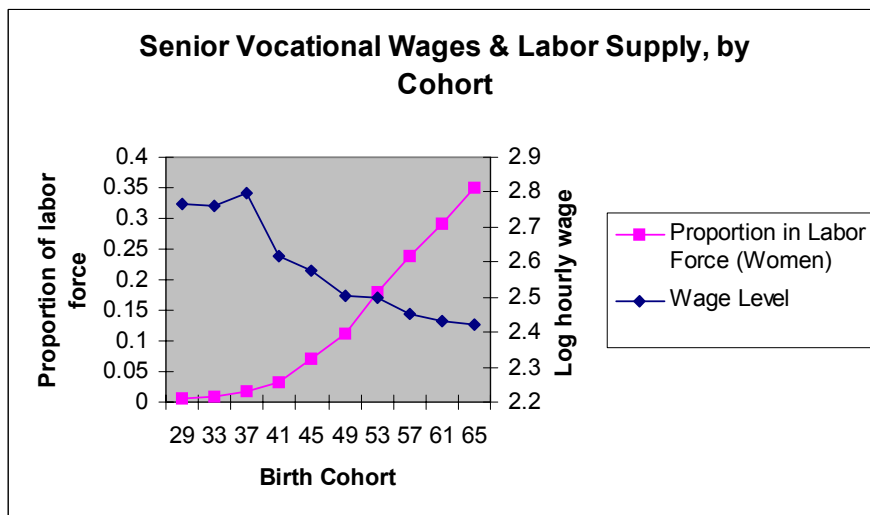


Figure 14:

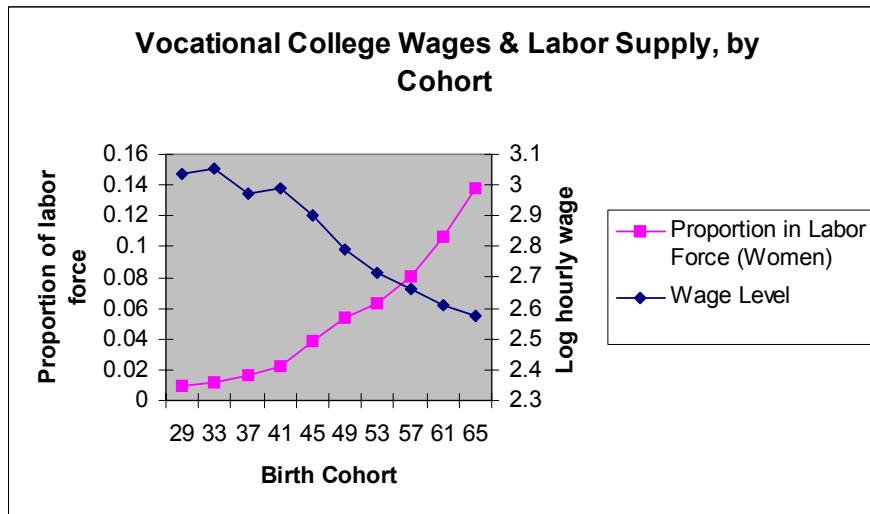


Figure 15:

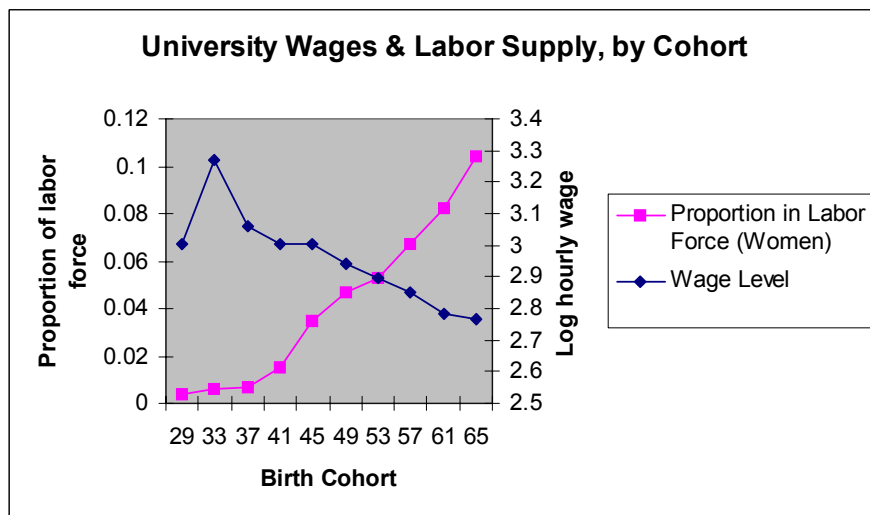


Figure 16:

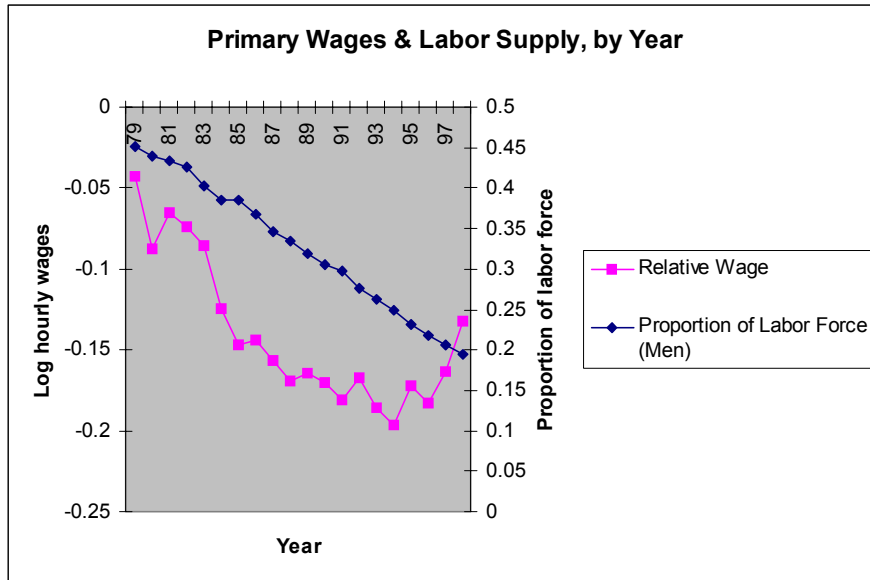


Figure 17:

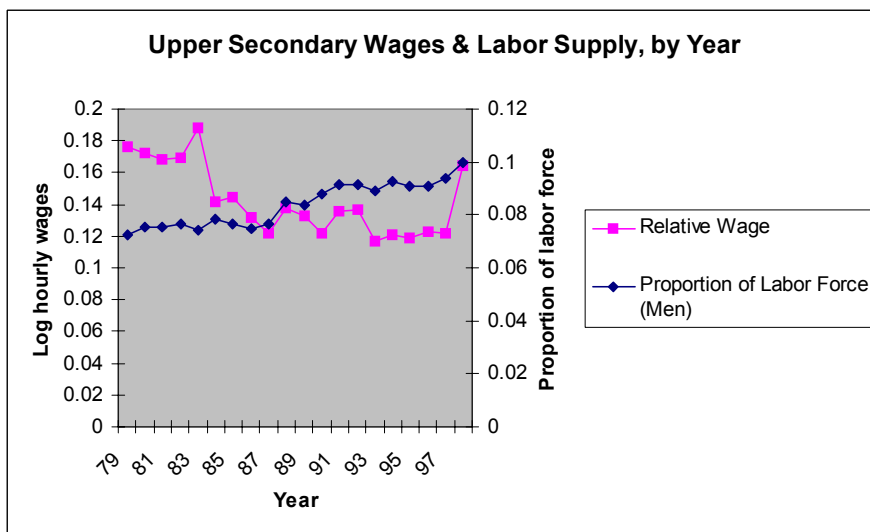


Figure 18:

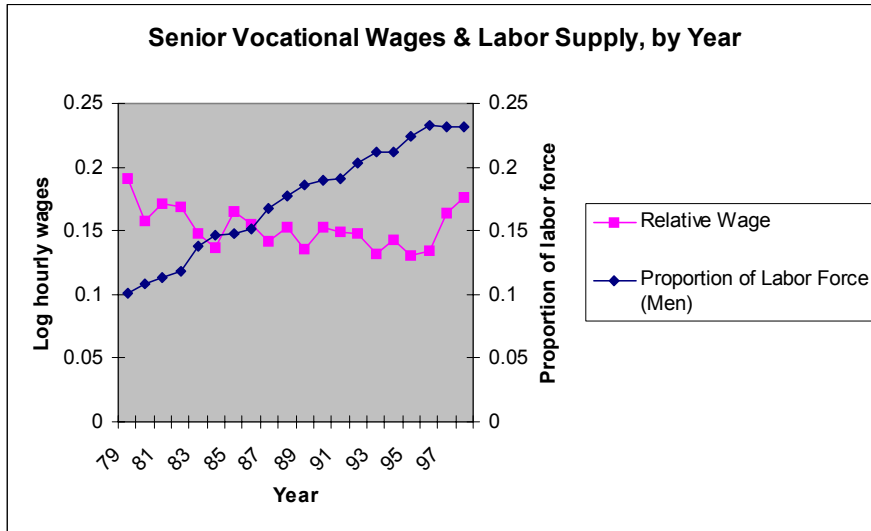


Figure 19:

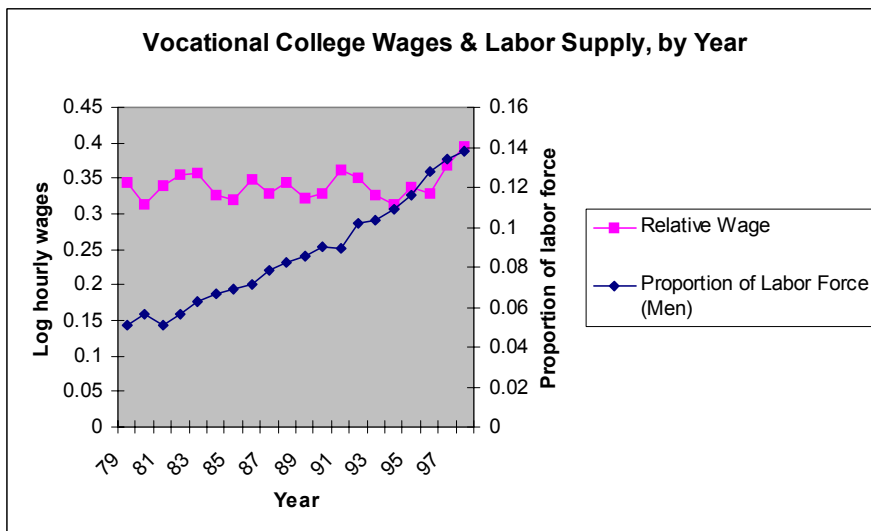


Figure 20:

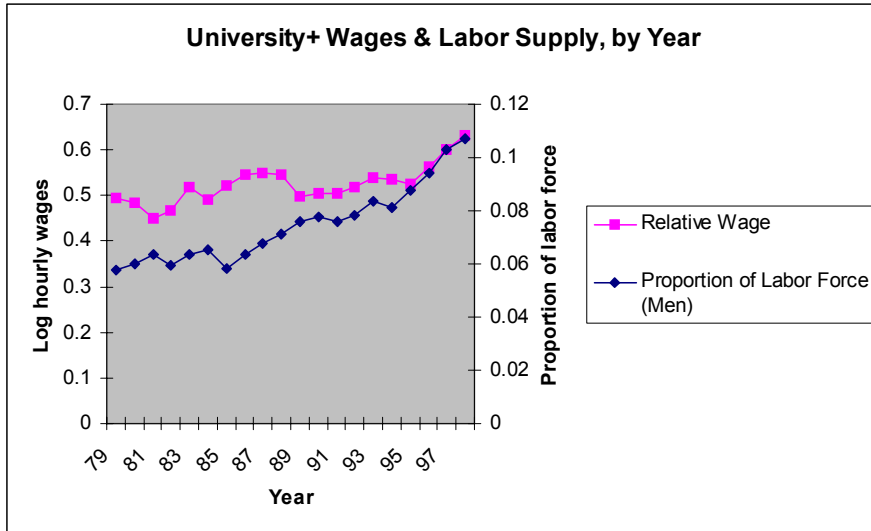


Figure 21:

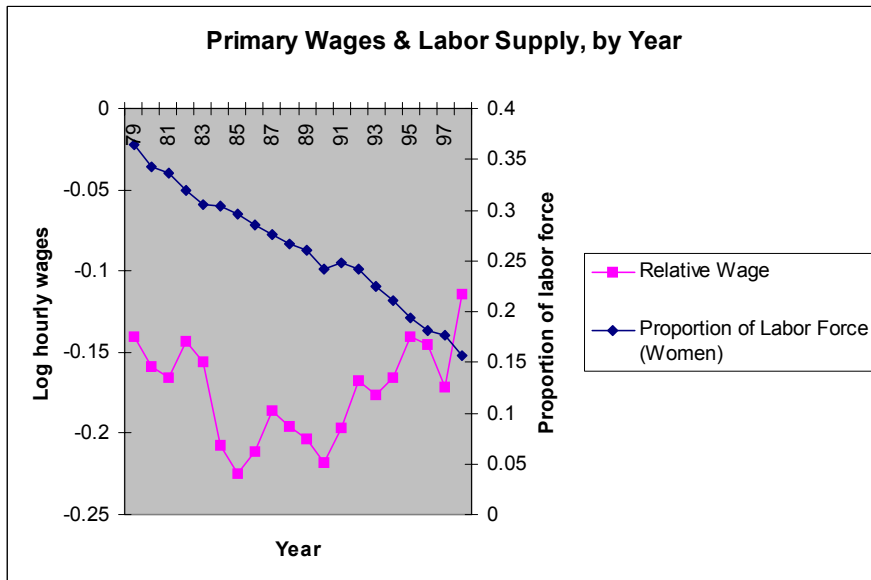


Figure 22:

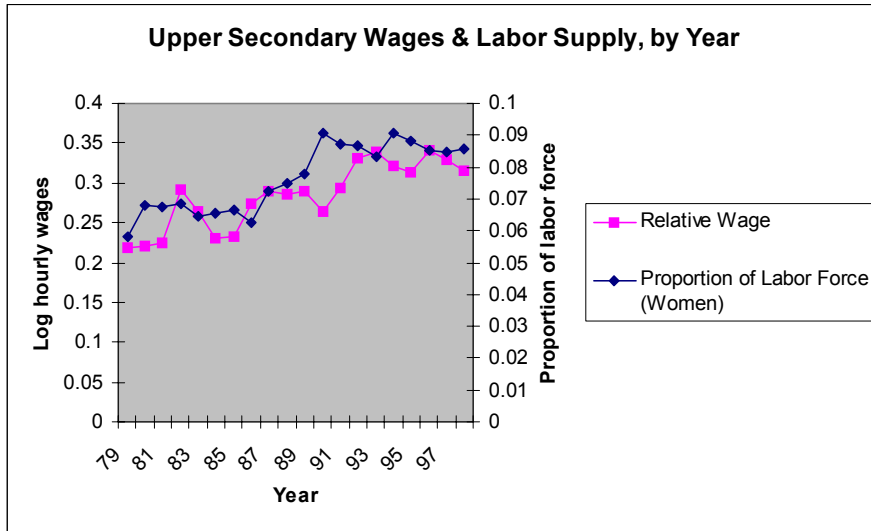


Figure 23:

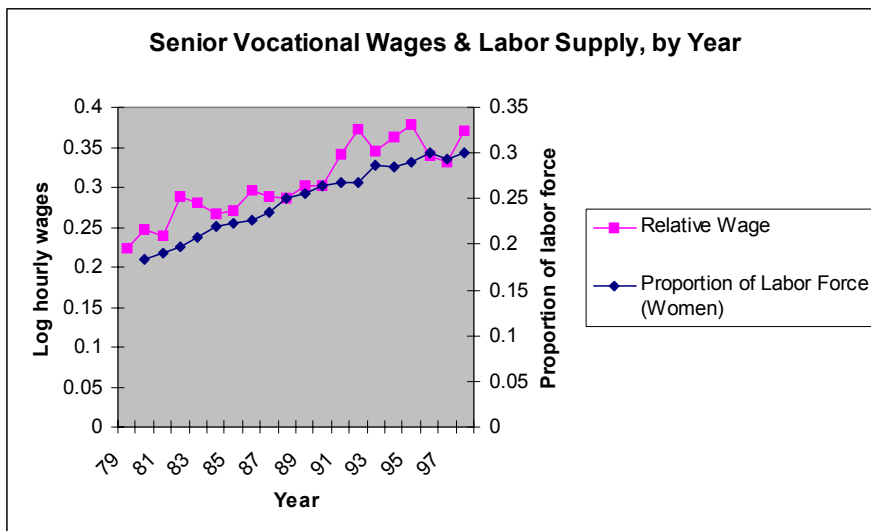


Figure 24:

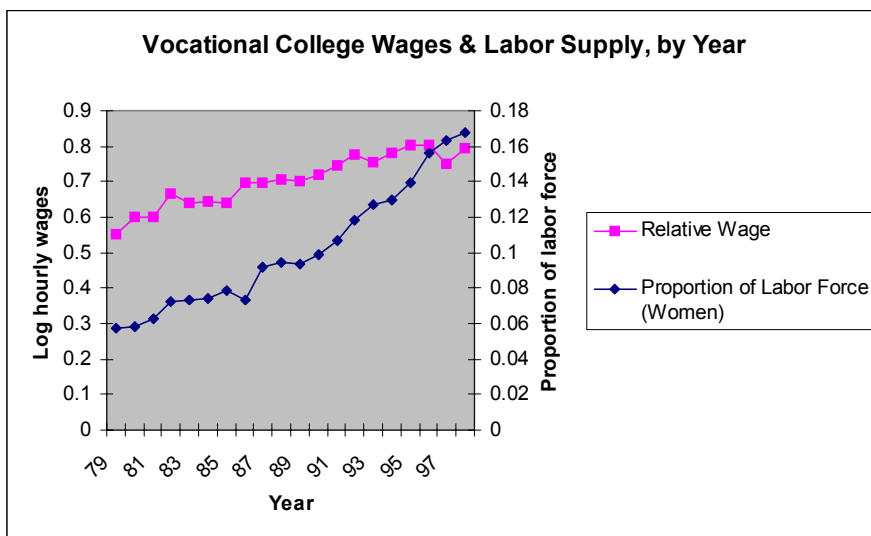


Figure 25:

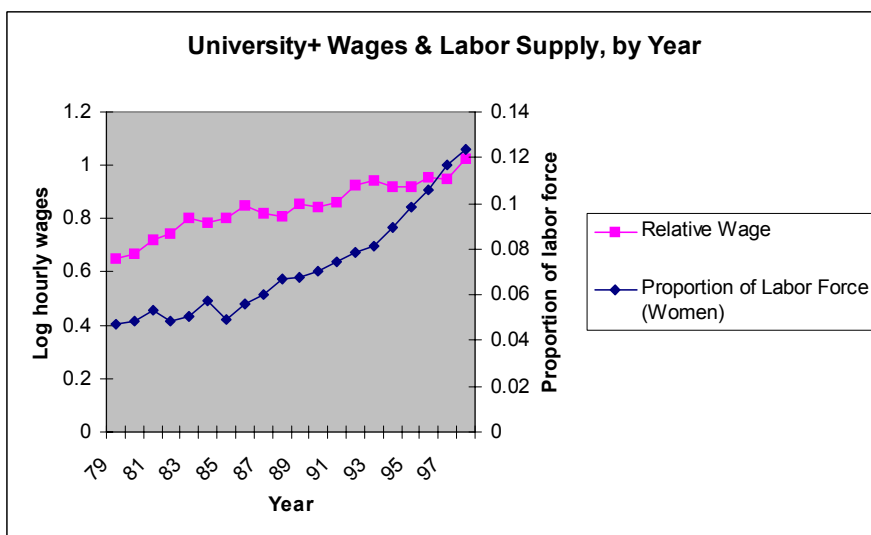


Figure 26:

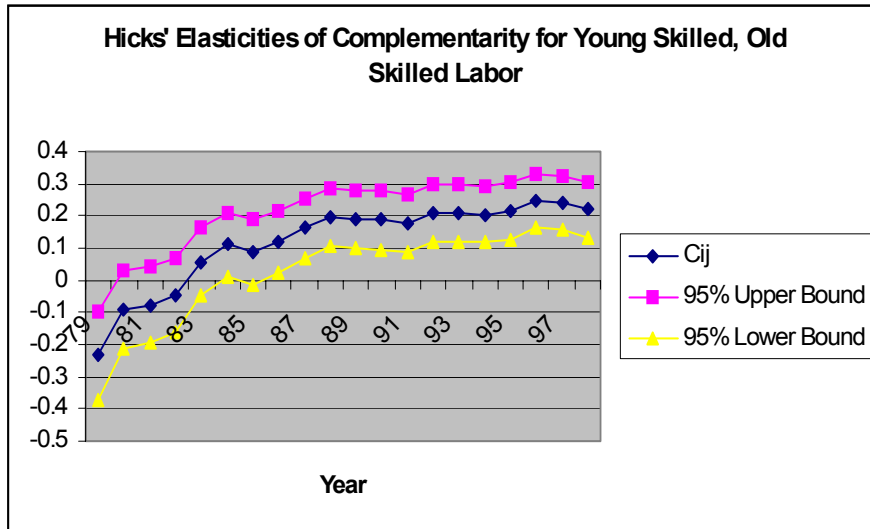


Figure 27:

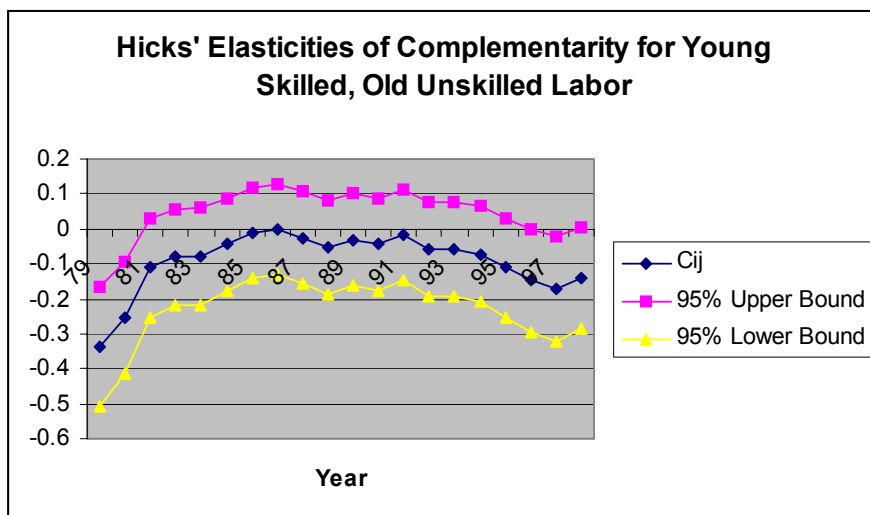


Figure 28:

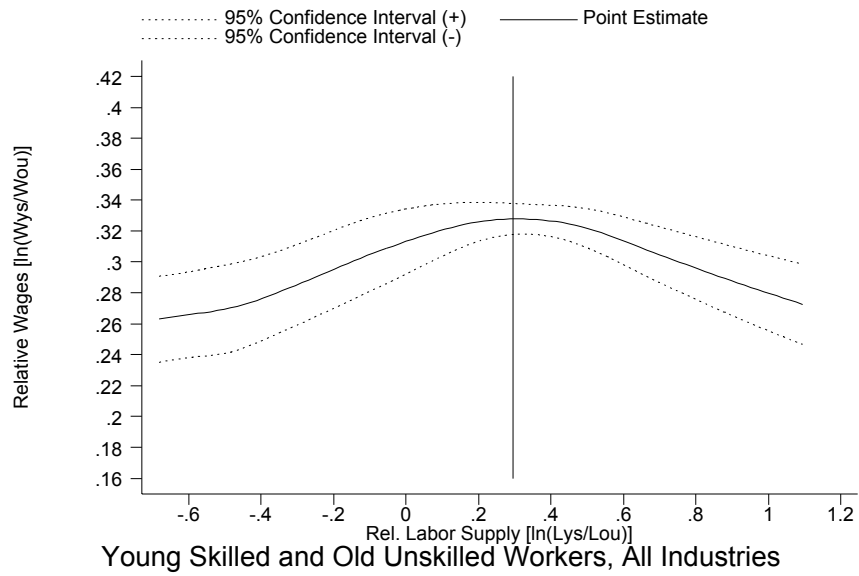


Figure 29:

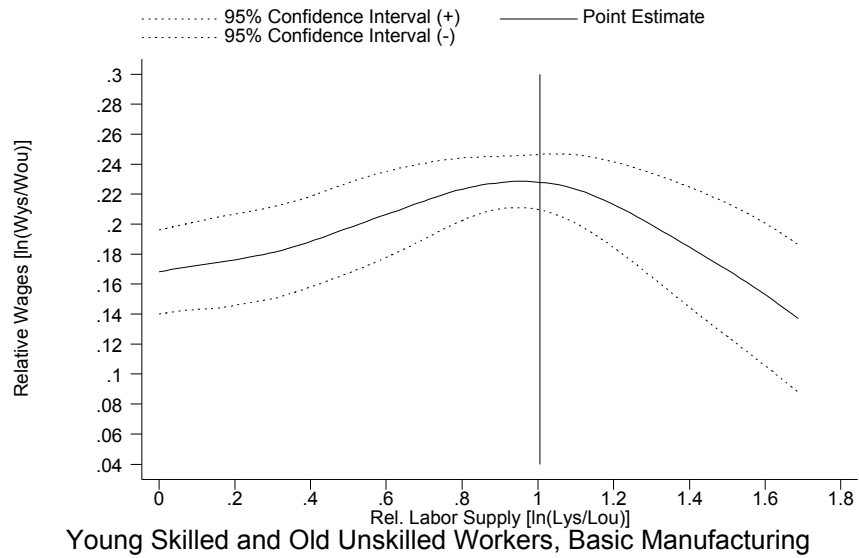


Figure 30:

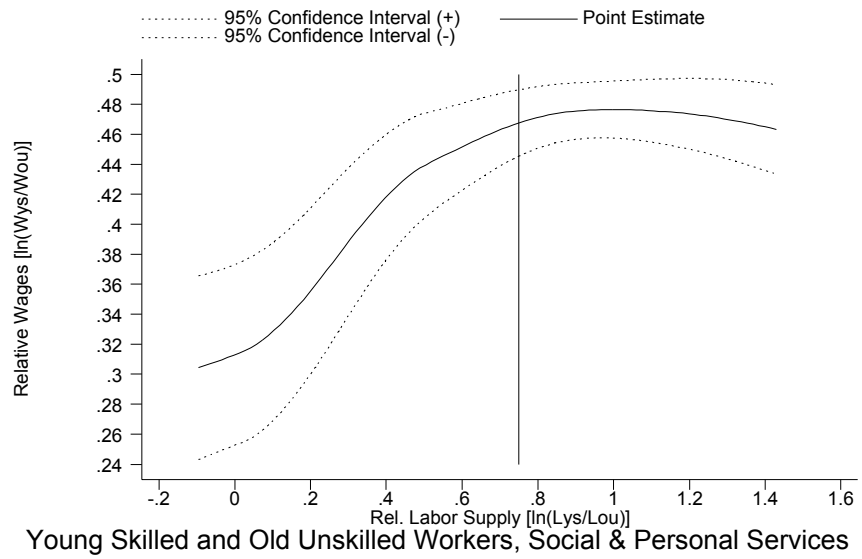


Figure 31:

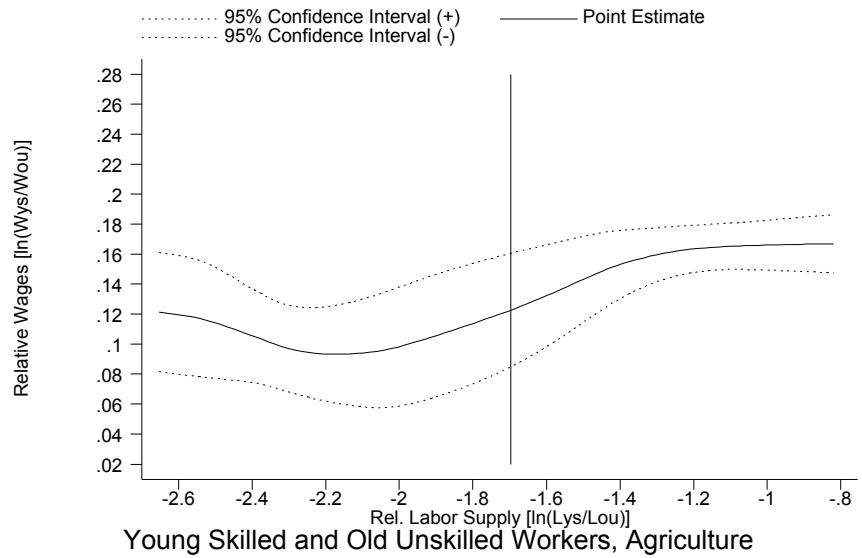


Figure 32: