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Assessing Less-Tangible Benefits of an Ergonomic Project

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Abstract: The purpose of this study was to assess the less-tangible benefits of an ergonomics project performed in a 300-mm wafer fabrication in Taiwan. The studied project was aimed at reducing the risk factors of musculoskeletal disorders (MSDs) faced by the wafer-handling workers. Firstly, the MSDs checklist was used to identify risk factors for the workers. The ergonomic intervention was then conducted. Subsequently, the willingness-to-pay (WTP) survey of the contingent valuation method was performed to quantify less-tangible benefits. The responded WTP results were analyzed to estimate the return on investment of this project, which was 43.6% and large enough to conclude that this project was cost-effectiveness. The marked decreases in the risk-factor found rate and the self-reported MSD rate in the post-intervention period proved that the intervention was effective in reducing the MSD problems. This paper is shown to be a good example to justify the worth of an ergonomics project.

Keywords: Cost effectiveness; musculoskeletal disorders; less-tangible benefit.

1. Introduction

Beevis indicated that though there have been reports on the cost or benefit impacts of ergonomic applications, few studies provided detailed information on the exact costs and benefits [1]. This fact implies that a lot of difficulties still need to be overcome in assessing the exact costs and benefits for ergonomic applications. Hendrick provided a specific method to collect costs and benefits for ergonomics projects [2]. He classified the costs into four categories: (1) personnel (e.g. outside consultant, internal personnel, and employee down time) costs, (2) equipment and material costs, (3) reduced productivity or sales, and (4) overhead. On the other hand, the benefits were classified as: (1) those associated with personnel, (2) those associated with materials and equipment, (3) those associated with increased sales, and (4) less-tangible benefits. It is easy to assign monetary values for these costs and benefits except the less-tangible benefits. Although the business case model can be applied to analyze the return on investment of an ergonomics project, it is futile if the less-tangible benefits can't be translated into economic values. For this reason, the assessment of the less-tangible benefits of an ergonomics project in the workplace is discussed in this study.

The less-tangible benefits derived from an

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ergonomics project in the workplace comprise reduction in fatigue or discomfort faced by workers, safety enhancing in the workplace, a fine reputation for the company, etc. These less-tangible benefits cannot be bought or sold in the marketplace, and therefore are considered as 'non-market goods'. Recently, non-market goods have been valued increasingly with the contingent valuation method (CVM). The CVM was originally developed in the environmental field to value public goods such as environmental quality and natural resources [3,4,5]. This method was later also applied to assess the economic value of changes in health care or safety condition [6,7,8].

The CVM adopts surveys to find out people's willingness-to-pay (WTP) for improvements on specific conditions. Respondents can also reply with the amount of compensation they are willing to accept (WTA) for a loss. Generally speaking, WTP is the appropriate measure in a situation where people want to acquire the goods, while WTA is the appropriate one if they voluntarily give up the goods [8].

The application of the CVM is considered appropriate for assessing the less-tangible benefits of an ergonomics project in the workplace [9], because ergonomic interventions also have the characteristics of public goods. To demonstrate the application, the data of an ergonomics project conducted in a 300-mm wafer fabrication (fab) in Taiwan were collected and analyzed. This project was aimed at preventing workers from developing the musculoskeletal disorders (MSDs) in manual wafer-handling operation. Firstly, the method for identifying the risk factors on the wafer-handling workers in the workplace was introduced, and the development and implementation of the ergonomic intervention were also expressed. Subsequently, the monetary value of the less-tangible benefits caused by the ergonomics project was estimated by the WTP survey, and the return on investment of the project was then assessed. Finally, the project effectiveness in reducing the ergonomics related risk factors and the number of MSDs was also discussed.

2. Methods

The studied ergonomics project was aimed at preventing workers from developing the MSDs in manual wafer-handling operation. The following demonstrates how to perform the project and how to assess its less-tangible benefits by the contingent valuation method. As general MSD related ergonomics studies, the first phase of this project was to identify the ergonomics related risk factors in the workplace.

2.1. Identification of ergonomics related risk factors

This ergonomics project was implemented at a 300-mm wafer fab of a semiconductor manufacturing company in Taiwan. The MSDs checklist developed by Occupational Safety and Health Administration was applied in identifying the risk factors for the wafer-handling workers [10]. This checklist includes three parts: Part A checks the risk factors that might lead to upper extremity problems, Part B checks the risk factors associated with back pain and lower extremity disorders, and Part C evaluates the risk factors about manual material handling tasks. The action limit is set at five risk score. If the evaluated risk score of Part A is equal to or over five, then ergonomic intervention should be performed to keep workers from the upper extremity problems. Besides, if the sum of the risk scores of Parts B and C is equal to or over five, then some improvement actions need to be taken to prevent workers from back pain and lower extremity disorders.

Three observers had been trained for two weeks before performing the field observation. It was confirmed that each observer was familiar with the standard check procedure and followed the identical evaluation criteria. The

studied workplace comprises eight areas: wafer start, lithography, diffusion, thin films, control wafer recycle, etch, ion implantation, and chemical mechanical planarization areas.

Around one fourth of the 300-mm wafer-handling workers in the fab were selected randomly to be observed. A total of 70 female workers were informed about the purpose of the investigation before conducting the field observation. These subjects were instructed to perform normal duties at their own pace and using their own posture. Their tasks include computer operation, wafer inspection, wafer container carrying, lifting, transporting, loading, and unloading. The wafer container is also called 'FOUP', an abbreviation of Front Opening Unified Pod, and weights about 9 kg while containing one lot (25 pieces). Each individual observation took about 30 to 45 minutes.

Each subject was asked to fill out the self-reported MSD position questionnaire after the individual observation. The surveyed body positions comprised arms, lower back, legs, and feet. If a studied worker had any MSD related symptoms, she should mark her injured body positions on the questionnaire. After the questionnaire survey, the self-reported MSD rate for each body position was calculated, which was defined as 'the number of workers suffered from the MSD on a specific body position in percentage of all of the surveyed subjects.

2.2. Designing the ergonomic intervention

The ergonomic intervention was developed based on the findings in the risk identification phase. The purpose of the ergonomic intervention was to eliminate the current main risk factors found in the risk identification phase. Ergonomics specialists and the manufacturing managers worked together to understand more fully the risk factors for the MSDs and to determine what can be done to prevent and treat them.

2.3. Valuation of the less-tangible benefits

The WTP questionnaire was designed to collect the workers' willingness-to-pay for this ergonomics project after intervention. In order to make each respondent understand the project, the first part of the WTP questionnaire summarized what changes had taken place after executing the ergonomic intervention.

The second part of the WTP questionnaire comprised questions about the satisfaction level and WTP for the less-tangible benefits accompanying the executed ergonomic intervention. The satisfaction levels were ranked using a ten-grade scale. Some default values of WTP were suggested for the respondent to choose from. The average WTP value of the sampled workers can be a good estimator of the population mean, if the sample size is large enough.

The third part of the questionnaire comprised questions about the socio-economic background of the workers. These questions were designed to collect the age, years of occupation, and monthly income of the respondent. Pearson product-moment correlation analysis was conducted to obtain the correlations between the WTP and the other quantitative variables.

2.4. Verifying the efficacy of the ergonomic intervention

In order to verify the efficacy of the ergonomic intervention, 35 workers were selected randomly from the original observed 70 workers to check their risk factors again during the first month of the post-intervention period. Comparisons between pre- and post-intervention were made to check whether the risk-factor found rate after intervention was markedly less than that before intervention. The risk-factor found rate was defined as 'the number of workers exposed to a specific risk factor in percentage of all of the sampled subjects observed'.

After the first year of the post-intervention period, the self-reported MSD rate for each body position was also collected again. Since it needs a long time to heal the MSDs, it is not comprehensive to collect the self-reported MSD rate immediately after the intervention. For this purpose, 35 survey subjects were selected randomly from the original observed 70 workers in the risk identification phase.

3. Results

3.1. Main risk factors found in the risk identification phase

The average risk score of the 70 subjects in Part A was 1.53, which was less than the action limit (i.e. risk score = 5). The summation of the mean risk scores in Parts B and C was 9.16, which was too high as compared to the action limit. The observation results indicated that the company should take some improvement actions immediately to eliminate the high risks about back pain and lower extremity disorders. Three main risk factors were observed in the 70 sampled subjects, as listed below:

(1) 80% of the sampled subjects were observed to transport a full FOUP manually over three meters.
(2) 61% of the sampled subjects were found to bend the trunk forward over 20° to take a FOUP from the lowest level of the rack, which was lower than knuckle height.
(3) 49% of the sampled subjects were observed to twist the trunk over 45° to take a FOUP from one side to the other.

3.2. Performing the ergonomic intervention

The ergonomic intervention included training program and posters propagation. The goals of the training program were to teach all of the 285 wafer-handling workers the ergonomic rules for handling wafers and to confer upon each worker the responsibility of maintaining a healthy posture at work (i.e. a self-directed intervention), with the final aim of reducing MSDs. Correct working posture, occupational and non-occupational risk factors for the MSDs, how to do when symptoms first occurred, and other related materials were also covered. The posters propagation was performed to remind workers of avoiding current ergonomic risk factors in the workplace. The ergonomic intervention was performed for one month after the risk identification phase.

3.3. Responses to the WTP survey

After the ergonomic intervention, the less-tangible benefits were evaluated instantly with the WTP survey questionnaire (Appendix 1). Because some workers didn't return the questionnaire, only 231 available respondents were surveyed from a total of 285 workers in this wafer fab. Table 1 summarizes the responded results of the WTP questionnaire survey. Most of the respondents (86%) believed that the training program was effective in reducing the musculoskeletal disorders. Besides, 85% of the respondents agreed that the posters propagation was effective to them. The responded averages and standard deviations of the satisfaction grades for the training program and the posters propagation were 65.8 ± 17.9 and 63.1 ± 17.9, respectively. These findings imply that the operators confirmed that this ergonomics project had positive effects on them.

The average willingness-to-pay (WTP) with its standard deviation for this project was 4,169 ± 5,340 TWD every year. The average age and the years of occupation of the respondents were 27.6 years and 3.6 years.

Table 2 shows the results of the correlation analyses between the WTP and each of the other studied factors. It indicates that the WTP for this ergonomics project was significantly correlated with the training program

satisfaction grade ($r=0.15$, $p<0.05$), posters propagation satisfaction grade ($r=0.13$, $p<0.05$), years of occupation ($r=0.23$, $p<0.05$), and monthly income ($r=0.22$, $p<0.05$).

Table 1. Summary of the WTP survey responses, n = 231

Questions	**Responses**				
	Absolutely yes	*Yes*	*Not sure*	*No*	*Absolutely no*
Is the training program effective?	19%	67%	9%	3%	2%
Is the posters propagation effective?	14%	71%	6%	5%	4%
	Mean	*Standard deviation*		*Minimum*	*Maximum*
Training program satisfaction grade	65.8	17.9		5	95
Posters propagation satisfaction grade	63.1	17.9		5	95
WTP (TWD[a])	4,169	5,340		0	19,000
Monthly income (TWD[a])	24,381	4,059		19,000	42,500
Age (Year)	27.6	5.8		19	45
Years of occupation (Year)	3.6	3.2		0.5	10

[a] TWD is Taiwan dollar

Table 2. The correlation analysis results, n = 231

	WTP	Training program satisfaction grade	Posters propaga-tion satisfaction grade	Age	Years of occupation
WTP	1				
Training program satisfaction grade	0.15*	1			
Posters propagation satisfaction grade	0.13*	0.87*	1		
Age	0.09	0.02	0.01	1	
Years of occupation	0.23*	–0.01	–0.03	0.69*	1
Monthly income	0.22*	0.03	0.01	0.52*	0.66*

*Correlation was significant at the α= 0.05 level

Table 3. The estimated ROI for the ergonomics project

Costs	**TWD**
1. Personnel costs	336,000
2. Equipment and material costs	312,000
3. Reduced productivity or sales	0
4. Overhead	155,400
Total cost (present value) [a]	803,400
Benefits	**TWD**
1. Those associated with personnel	0
2. Those associated with materials and equipment	0
3. Those associated with increased sales	0
4. Less-tangible benefits	1,188,384
Total benefit (present value) [b]	1,153,782
Return on investment	**43.6%**

[a] The years of useful life of this investment was considered as only one year.
[b] Discount rate was 2.98%

3.4 Estimating the return on investment of the project

The cost and benefit data were collected and classified using Hendrick's method, as

mentioned previously [2]. Table 3 summarizes the total investment cost and the total benefits derived from this ergonomics project. The costs were retrieved from the historical accounting data, and their sum was 803,400 TWD. Since there were no benefits associated with personnel, materials, equipments, or increased sales after ergonomic intervention, these benefit categories were assigned zero values. The total less-tangible benefits were estimated from the results of the WTP survey. Taking the average WTP of the 231 workers as the estimator for the population mean, the total amount of all workers' WTPs every year can be calculated as 4,169 × 285 = 1,188,165 TWD every year. The discount rate was 2.98% and the present value of the total benefit was 1,188,165 / 1.0298 = 1,153,782 TWD. The return on investment (ROI) was calculated by dividing the net present value (NPV) by the present value of total costs, where the NPV was defined as the present value of total benefits minus the present value of total costs. Finally, the ROI was calculated as (1,153,782 – 803,400)/ 803,400 × 100% = 43.6%.

3.5. Comparisons between pre- and post-intervention

3.5.1. Risk-factor found rate

During the first month of the post-intervention period, the risk-factor found rate for each of the three main risk factors was obviously less than that in the pre-intervention period, as presented in Fig. 1. The reduction in the risk-factor found rate for transporting a full FOUP manually over three meters was the greatest (from 80% to 29%), followed by those for twisting the trunk over 45° (from 49% to 17%) and bending the trunk forward over 20° (from 61% to 43%).

3.5.2. Self-reported MSD rate

After the first year of the post-intervention period, the self-reported MSD rate for each of the four body positions was lower than that in the pre-intervention period, as shown in Fig. 2. The decrease in the self-reported MSD rate for legs was the greatest (from 47% to 28%), followed by those for lower back (from 27% to 19%), feet (from 37% to 31%), and arms (from 19% to 17%).

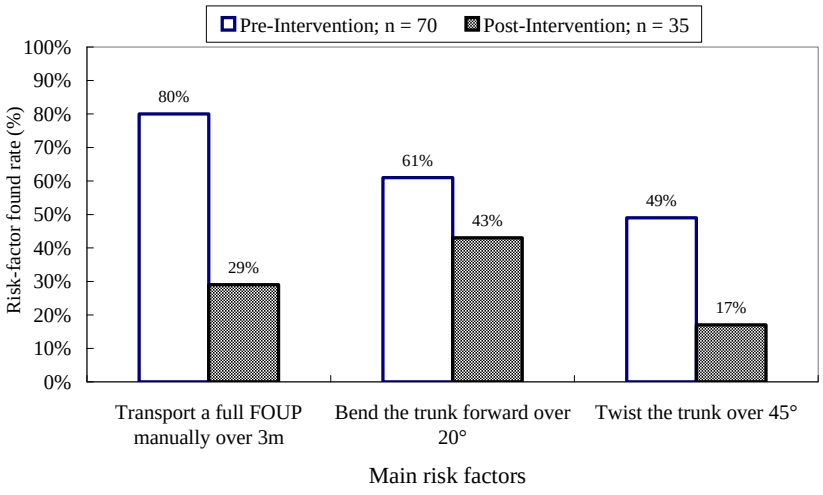

Figure 1. The risk-factor found rate in the pre- and post-intervention periods

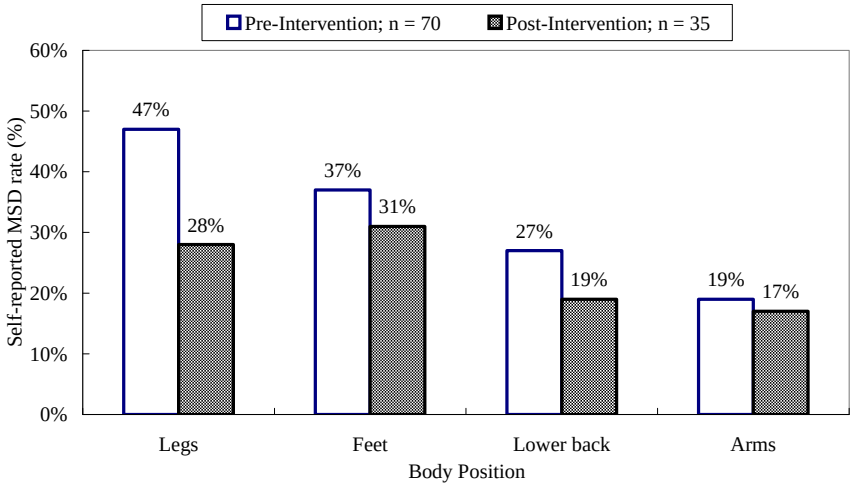

Figure 2. The self-reported MSDs rate in the pre- and post-intervention periods

4. Discussion

4.1. Economic efficacy of this ergonomics project

The ROI of this project had estimated to be 43.6% demonstrating good economic efficacy for the ergonomic intervention. But, it should be noted that the less-tangible benefits derived from the WTP responses are not actual economic benefits until the workers really pay the money. In general real cases, the employers usually just want to understand whether the ergonomic intervention is worth investing, instead of getting the money paid by the employees.

This study provided a timesaving and easy method to assess the economic benefits of ergonomics projects in the workplace. In the demonstrative example, only one month was required to conduct the WTP survey after the ergonomic intervention. In addition, the ROI of the project can also be estimated easily. The estimated ROI can be considered as an important index to criticize the economic value of the ergonomics project in the early year.

Some previous studies have indicated that it took several years to fully recognize the economic benefits of the ergonomics project by comparing MSD related compensation costs and days lost between the pre- and post-intervention periods [11,12]. Unfortunately, most of the workers in Taiwan were ashamed to ask compensation while suffering work related MSDs. They usually paid the medical treatment by themselves and worked as usual when they suffered musculoskeletal discomfort or pain. Few compensation costs and days lost were reported and filed before, and in consequently, these data were not adequate to assess the real economic benefits of the ergonomics project in the present study.

4.2. Factors affecting WTP

The results of the correlation analyses indicated that the higher satisfaction grade the worker rated the ergonomic intervention, the more WTP she responded. Besides, the satisfaction grade of the training program was significantly correlated with that of the posters propagation ($r=0.87$, $p<0.05$). This is owing to that the content of the posters was mostly extracted from the lectures of the training program.

In addition to the satisfaction level for the ergonomic intervention, the years of occupation and monthly income of the respondent were also proven to be slightly relevant to the

WTP. This may be due to that the workers who had higher income and more work experience were willing to pay more for the training program.

4.3. The reduction in risk-factor found rate after intervention

The purpose of this ergonomic intervention was to prevent or reduce the risk factors associated with the onset of MSD. The comparisons between pre- and post-intervention show that the most obvious decrease among all risk-factor found rates occurred in transporting a full FOUP manually over three meters (from 80% to 29%), as shown in Fig. 1. This was due to that a markedly high percentage of the workers could remind themselves of using trolleys to transport FOUPs and they realized this manner is good for health after the ergonomic intervention.

In the risk factor of twisting the trunk over 45°, a considerable reduction in this risk-factor found rate was observed (from 49% in the pre-intervention period to 17% in the post- intervention period). This phenomenon could also be explained by the effect of the ergonomic intervention. The training program taught the workers to move their feet to take a FOUP from one side to the other, instead of twisting the trunk.

The decrease in the risk-factor found rate for bending the trunk forward over 20° was not as obvious as those for the other two main risk factors, as shown in Fig. 1. This was due, in part, to the limitations in rack height and the quick-tempered workers. Although the workers had been taught to squat to take the FOUP from the lower rack, about 43% of the sampled subjects still bent the trunk forward quickly to take the FOUP. These observations recommended that replacing the lower racks with adequate ones would be a fundamental solution for eliminating this risk factor.

4.4. The reduction in self-reported MSD rate after intervention

The absence of a control group in this longitudinal research design makes it difficult to ascertain the direct influence of the ergonomic intervention on the reduction of MSD. Because no changes in the hardware and administrative instruments were made except the ergonomic intervention during the study period, the change in MSD rate after intervention could be mainly attributed to this ergonomics project. The greatest decrease among all self-reported MSD rates was on the legs (from 47% to 28%), as shown in Fig. 2. This long-term survey result can be explained by the marked reduction in the legs related risk-factor found rate, i.e. transporting a full FOUP manually over three meters (Fig. 1). It is believed that the training program and posters propagation were mostly effective in preventing the workers from lower extremity disorders.

Although the self-reported MSD rates of lower back, feet, and arms after the first year of the post-intervention period were all less than those in the pre-intervention period, the differences were not as much as that of legs. It means that this ergonomic training program seemed to have limited effect on the reduction of the risk factors associated with lower back, feet, and arms. However, other ergonomic interventions, such as hardware improvements and administrative changes, could be also considered to be performed in the future [11,13,14].

The findings of considerable drops in the self-reported MSD rates after the ergonomic intervention are in agreement with recently studies associated with the positive effect of ergonomic training program on the reduction in MSDs [14,12,15]. Notably, these findings are also consistent with the WTP survey results that indicated a relatively high percentage of the respondents (86%) agreed the training program was effective to reduce the MSDs (as shown in Table 1).

Because of the effectiveness of the ergonomics project, the company has been de-

cided to perform the training program every year, and to incorporate the training lectures into the new-employee training course for the wafer-handling task.

5. Conclusions

From this evidence study, we concluded that the contingent valuation method is an efficient method to assess the less-tangible benefits of an ergonomics application in monetary terms. Only one month was required to conduct the willingness-to-pay (WTP) survey after the ergonomic intervention. The studied ergonomics project performed in a 300-mm wafer fabrication was very worth doing because of the return on investment was considerable high (43.6%). After the first year of the post-intervention period, the greatest decrease among all self-reported MSD rates was on the legs (from 47% to 28%), which could be explained by the marked reduction (from 80% to 29%) in the risk-factor found rate associated with legs, i.e. transporting a full FOUP manually over three meters. These findings proved that the training program and posters propagation did help the workers to reduce ergonomics related risk factors and thus reduce the occurrence of MSD on them.

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Appendix 1: Less-tangible benefit evaluation questionnaire

Part 1. Project understanding

Ergonomic application project for improving 300-mm wafer handling operation

1.1 Ergonomic risk identification

(1) Workers usually transported a full FOUP manually over three meters. This risk factor would lead to lower back pain and lower extremity disorders.

(2) Workers usually bent the trunk forward over 20° to take a FOUP from the lowest level of the rack, which was lower than knuckle height. This would be the main cause of lower back pain.

(3) Workers would like to twist their trunk over 45° to take a FOUP from one side to the other side. This harmful posture might lead to waist and back disorders.

1.2 Improvement activities (Ergonomic intervention)

(1) The training program was provided to teach all of the 285 wafer-handling workers the ergonomic rules for handling wafer and confer upon each worker the responsibility of maintaining a healthy posture as working in the 300-mm wafer fabrication.

(2) The posters propagation was tried to remind workers to avoid potential ergonomic risk factors in the workplace. They were posted near the clean room entry.

Part 2. Satisfaction level and WTP

2.1 Is the training program effective to reduce the musculoskeletal disorders?

☐Absolutely yes ☐Yes ☐Not sure ☐No ☐Absolutely no

2.2 Is the posters propagation effective to reduce the musculoskeletal disorders?

☐Absolutely yes ☐Yes ☐Not sure ☐No ☐Absolutely no

2.3 Which grade can represent your satisfaction level about the training program?

☐0~10 ☐10~20 ☐20~30 ☐30~40 ☐40~50

☐50~60 ☐60~70 ☐70~80 ☐ 80~90 ☐90~100

2.4 Which grade can represent your satisfaction level about the posters propagation?

☐0~10 ☐10~20 ☐20~30 ☐30~40 ☐40~50

☐50~60 ☐60~70 ☐70~80 ☐ 80~90 ☐90~100

2.5. How much money (TWD) are you willing to pay every year for obtaining the benefits from the above-mentioned improvement activities?

☐Zero ☐1000 ☐3000 ☐5000

☐7000 ☐9000 ☐11000 ☐13000

☐15000 ☐17000 ☐19000

Part 3. Socio-economic background

3.1. How old are you?

☐Under 20 ☐21~30 ☐31~40 ☐41-50 ☐Over 50

3.2. How long have you been working in this company?

☐Under one ☐1~2 ☐3~4 ☐5~6 ☐7~8 ☐Over 9

3.3. What's your average monthly income? (TWD)

☐Under 20000 ☐20000~24999 ☐25000~29999

☐30000~34999 ☐35000-39999 ☐40000 and above

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