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Applied Economics and Policy Research in Health, Dairy, and Fishery Industries

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Applied Economics and Policy Research in Health, Dairy, and Fishery Industries

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Abstract

Chapter 1: With aging populations, policymakers are encouraging people to work longer to sustain the financial stability of social security systems. However, the effect of postponing retirement on mental health remains uncertain. The US Social Security Amendments of 1983 raised the social benefit age by two months each year for those cohorts born after 1937. These amendments provide a unique opportunity to assess the causal effect of retirement age on mental health. Using data from the 1994 to 2012 waves of the US Health and Retirement Survey, this paper instrumented retirement age with the amendments to control for the biases caused by the endogeneity between retirement age and mental health. This instrumental variable estimation showed that a slight gradual rise in retirement age was beneficial to retirees' mental health.

Chapter 2: There has been increasing awareness by policymakers of the need to identify the key factors that affect dairy farmers' management decisions. This study utilizes a theoretic model to illustrate why Canadian farmers might be hesitant about disease control under the supply management system and how peer pressure can induce farmers to improve their efforts. An experiment based on a Johne's disease scenario was implemented among Canadian dairy farmers to test the theoretic model conclusions. Both the theoretic model and the pilot experiment suggest that without a strong external monitoring policy, optimal effort level cannot be achieved.

Chapter 3: The Norwegian purse seine fishery has employed multiple rights-based regulatory instruments to limit the fishing effort. Following the management reforms, this fleet shrunk substantially while the capital investment in this fleet expanded substantially. The comprehensive efficiency change in an era of revolutions are worth exploring, yet ambiguous. This paper evaluates the production and cost efficiency changes among the Norwegian purse seiners using data on Norwegian purse seiners for the period of 1994-2013. The stochastic frontier analysis shows that the purse seiners could reduce production cost significantly by eliminating inefficiencies. Meanwhile, both technical and allocative efficiencies are improving over time. A further investigation suggests that the transferable quota policies had limited impact on efficiencies.

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Chapter 1

Retirement Age and Mental Health: Postponing Retirement May Improve Mental Health

1.1 Introduction

Given the increasing life expectancy and aging populations, many countries have been revisiting social security policies to encourage people to retire later (Gustman & Steinmeier, 1985; Mastrobuoni, 2009; Staubli & Zweimüller, 2013). Countries such as Australia, Norway, and the US have raised the social benefit age to stimulate seniors to work longer. It is worth noting that the success of related policy changes partly depends on the effect of retirement age on health, particularly mental health. If working longer imposes a mental burden on workers, then health expenditures would increase. The increased health expenditures would offset, in part, the benefit of those policies in relieving the fiscal difficulties of social security systems.

Existing studies have indicated that retirement has a significant impact on mental health, but these studies have generated conflicting conclusions. Some studies have claimed that retirement reduces stress and therefore improves mental health (Drentea, 2002; Eibich, 2015; Latif, 2011; Midanik, Soghikian, Ransom, & Tekawa, 1995). Nevertheless, others have argued that retirement is associated with a higher possibility of mental illness due to significant lifestyle changes (Dave, Rashad, & Spasojevic, 2008; Mckenzie, Gunasekara, Richardson, & Carter, 2014; Mein, Martikainen, Hemingway, Stansfeld, & Marmot, 2003; Vo et al., 2015).

However, very few studies have focused on the effect of retirement age on mental health in particular. Some studies have reported a positive association between retirement age and mental health (Gill et al., 2006; Sahlgren, 2013), but limited studies have identified a causal effect. The major challenge in identifying the causal effect of retirement age on mental health lies in endogeneity, i.e., retirement age could affect mental health, but people may choose retirement ages based on their mental health wellbeing.

The existing literature has adopted the instrumental variables (IV) approach to address this endogeneity (Calvo, Sarkisian, & Tamborini, 2013; Dave et al., 2008; Hagen, 2016). All of these studies concluded that a higher retirement age leads to better mental health. Dave, Rashad, and Spasojevic (2008) used a spouse's retirement status as a predictor of a respondent's retirement status. However, it is possible that a spouse chose to retire because of their own health condition or because of the respondent's mental health condition. Calvo, Sarkisian, and Tamborini (2013) instrumented retirement age with both a benefit age increase and an early retirement offer from employers. However, the reason why an employer offered an early retirement could be directly related to an employee's mental health. In addition, this study did not account for the potential link between mental health and self-assessed health (SAH). Hagen (2016) employed a benefit age change in Sweden as the IV for retirement age. The Swedish reform was applied to local government workers, whereas Hagen used private sector workers as the study's control group. Therefore, it is possible that Hagen's results were biased by the working sector difference.

The current study examined the causal effect of retirement age on mental health. The identification strategy utilized the US Social Security Amendments of 1983 as the IV for retirement age, while controlling for SAH and other influencing factors. The Social Security Amendments of 1983 gradually increased the normal retirement age from 65 to 66 years old and decreased the amount of the benefit received if one claims an early retirement at 62 years old. The amendments are implemented according to birth year, regardless of the health condition or working sectors of seniors. Therefore, the 1983 amendments can be utilized as a natural experiment to investigate how retirement age affects mental health.

The remainder of this paper is organized as follows. Section 2 describes the study setting and data. Section 3 provides the empirical methodology, and the results are presented in section 4. A discussion of mechanisms and mental health changes follows in section 5, and section 6 concludes the paper.

1.2. Study Setting and Data

1.2.1 Study Setting

1.2.1.1 The US Social Security Amendments of 1983

When it was established in 1935, the US Social Security Administration set the benefit age as 65. At that time, the American life expectancy at birth was approximately 60 years, and the expectation at age 60 was to live to 72 (Wiatrowski, 2001). As the life expectancy increased dramatically, the cost of the Social Security system expanded. To overcome this financial difficulty, in 1983, Congress signed amendments to "gradually increase the eligibility age for full benefits from age 65 to age 66 in 2009 and age 67 in 2017" (Kollmann, 2000). Starting in 2000, the full benefit age increased 2 months each year for those cohorts born after 1937 until the benefit age reached 67. In addition, Americans can collect an "Age 62 Benefit" when they reach 62 years of age, with an approximate 20% reduction in their monthly benefit for claiming Social Security before they reach the full benefit age. However, the 1983 amendments further reduced the monthly benefit for people who claim the Age 62 Benefit. The detailed full benefit age schedule and that for the Age 62 Benefit for the affected cohorts are illustrated in Table 1.1.

1.2.1.2 Validity of the Instrumental Variable

First, substantial literature has documented that the benefit age has a significant impact on individuals' retirement age decision (Andrew, 1998; Bongsang, Adam, & Perelman, 2012; Börsch-Supan & Schnabel, 1998; Coile & Gruber, 2007; Mastrobuoni, 2009; Neumark & Powers, 2005) and that raising the benefit age could raise the average retirement age (Barbara & Axel, 2004; Fields, 1984; Gustman & Steinmeier, 1985). In particular, Mastrobuoni (2009) found that the average retirement age of the affected cohorts of the 1983 amendments has increased one month every year.

Second, the 1983 amendments are exogenous to mental health. The major incentive of the amendments is to address the financial problems of the system (Martin & Weaver, 2005). This benefit age change is subject to the year of birth regardless of mental health conditions. The year 1937 was set as the threshold for financial purposes rather than for health or mental health interests. Therefore, the amendments could trigger retirement decision changes but not directly affect mental health, thereby making it a valid IV for retirement age.

Table 1. 1: Full retirement and Age 62 benefit by year of birth

Year of Birth	Full Retirement benefit Age	At age 62, the retirement benefit would be reduced by
1937 or earlier	65	20.00%
1938	65 and 2 months	20.83%
1939	65 and 4 months	21.67%
1940	65 and 6 months	22.50%
1941	65 and 8 months	23.33%
1942	65 and 10 months	24.17%
1943-1954	66	25.00%
1955	66 and 2 months	25.83%
1956	66 and 4 months	26.67%
1957	66 and 6 months	27.50%
1958	66 and 8 months	28.33%
1959	66 and 10 months	29.17%
1960 and later	67	30.00%

Note. Data source: The United States Social Security Administration

1.2.2 Data

Data were obtained from wave 2 to wave 11 (1994-2012) of the US RAND Health and Retirement Study (HRS), longitudinal file. The first wave of HRS was excluded because it did not report the mental health indicator. The HRS is a longitudinal biennial panel survey that includes 37,317 individuals who are nationally representative of Americans aged 50 and above (RAND Health and Retirement Study, 1992-2012). The HRS collected 373,172 observations from the 37,317 individuals between 1994 and 2012. We extracted the data on the mental health indicator, SAH, retirement age, current ages at the survey, gender, race, education, marital status, veteran status, and financial information.

The 1983 amendments affected almost all Americans born after 1937 but not those born before 1937 (Duugan, Singleton, & Song, 2007). For this reason, the treatment and control groups were formed utilizing the threshold of 1937. Following Mastrobuoni (2009), those individuals born between 1938 and 1941 were categorized as the treatment group, and those individuals born between 1928 and 1937 were categorized as the control group. We can expect an average jump in retirement age due to the amendments, but we do not expect notable alterations in the mental health of individuals born in those specific years (Calvo et al., 2013; Neumark & Powers, 2005). The sample comprised 1,237 treated observations and 3,111 controlled observations.

The study sample was selected according to the following four criteria. First, Americans are eligible to start collecting Social Security benefits as early as age 62 and as late as age 70. Therefore, the sample was restricted to respondents aged between 62 and 70 because the amendments would affect these respondents most directly. Imposing this age restriction could also reduce the measurement bias associated with larger age variations. Second, only those respondents who retired between age 62 and age 66 were included to ensure that the amendments were relevant. As mentioned above, Americans can start to claim their benefit at age 62. Meanwhile, in 2012 (the last wave of HRS used here), the full benefit age for the youngest cohorts in the sample was 66 (Table 1.1). That is, if the respondents chose to retire before age 62 or after age 66, their decisions were unlikely subject to the amendments. Third, the respondents who applied for Social Security Disability Insurance and/or Supplemental Security Income were excluded. Finally, respondents who reported a poor health condition or experienced health deterioration were excluded. The last two criteria were employed to mitigate the concern that some individuals might use a self-assessed health condition as a justification for retirement.

1.2.2.1 Defining Retirement

In the HRS, retirement status is surveyed by multiple questions as follows: (1) “whether retired” is asked of the respondents; if the answer to (1) is “yes”, then (2) the time of retirement is collected; also, (3) retirement is reported in the question regarding “labor force status”. The current study defined a respondent as being retired if his or her labor force status is “retired” and if he or she provided the time of retirement.

1.2.2.2 Measuring Mental Health

The HRS measures mental health with a Center for Epidemiologic Studies Depression (CES-D) scale. The CES-D is derived from six questions about negative feelings and two questions about positive feelings. Respondents evaluate the frequencies of their feelings on a scale from 0 (rarely or none) to 3 (most or almost all the time). The sum of the six negative-feeling frequencies minus the two positive-feeling frequencies results in the CES-D score. The total score ranges from 0 to 8, with a higher score indicating a worse mental health condition.

1.3 Methodology

1.3.1 The Econometric Model

The following ordinary least square (OLS) specification was employed as a baseline model:

(1.1) $\mathrm{MH}_{it} = \mathrm{a} + \mathrm{b} * \mathrm{r}_i + \mathrm{c} * \mathrm{X}_i + d * \mathrm{V}_{\mathrm{it}} + e_{it}$

where the independent variable of mental health (MH) was measured by the CES-D, and r_i represents the retirement age of respondent i. X_i is a vector of time-invariant covariates, and V_{it} is a vector of time-varying covariates. Parameter b illustrates the correlation between retirement age and mental health. However, the estimation of b cannot provide a causal inference because of endogeneity. There are two potential sources of endogeneity, namely, uncontrolled confounders and reverse causality.

Uncontrolled confounders refer to unobservable factors that might influence both retirement age and mental health. Dave et al. (2008) mentioned that a health shock and poor self-reported health could cause endogeneity in the analysis of retirement effect on health. To address this concern, those respondents who reported a poor health condition, experienced a health deterioration, or received disability pensions were dropped, as discussed in section 2.2.

Reverse causality means that, although the retirement age may affect mental health, it is possible that people choose to retire earlier because of a worse mental health condition, or vice versa. With reverse causality, the effect of retirement age on mental health could be overestimated. The current study utilized the 1983 amendments to instrument retirement age to overcome reverse causality. As discussed in section 2.1, the 1983 amendments are a valid instrumental variable for retirement age because they affect retirement age directly, but they affect mental health only through retirement age.

Additionally, because mental health might vary by age, this study included an age-fixed effects analysis, in addition to the basic IV approach. The following first and second stage equations were estimated:

(1.2) $\mathrm{r_i} = \mathrm{a_0} + \mathrm{a_1} * \mathrm{Z} + \mathrm{a_2} * \mathrm{X_i} + \mathrm{a_3} * \mathrm{V_{it}} + \sum_{\mathrm{m=1}}^{\mathrm{M}} \mathrm{a_{4m}} * \mathrm{A_m} + \epsilon_{\mathrm{it}}$

$$Z = \begin{cases} 0, \textit{if born between } 1928 \textit{ and } 1937 \\ 1, \textit{if born in } 1938 \\ 2, \textit{if born in } 1939 \\ 3, \textit{if born in } 1940 \\ 4, \textit{if born in } 1941 \end{cases}$$

(1.3) $\mathrm{MH_{it}} = \mathrm{b_0} + \mathrm{b_1} * \mathrm{r_i} + \mathrm{b_2} * \mathrm{X_i} + \mathrm{b_3} * \mathrm{V_{it}} + \sum_{\mathrm{m=1}}^{\mathrm{M}} \mathrm{b_{4m}} * \mathrm{A_m} + \varepsilon_{\mathrm{it}}$

In equation (1.2), Z represents the instrumental variable that reflects the intensity of the 1983 amendments on different cohorts. Z takes a value of zero if the birth year is before 1938 and a positive value otherwise. There are a number of M age groups, and A_m is a dummy variable indicating age. V_{it} is a vector of time-dependent covariates, including marital status, accumulated wealth, SAH, previous mental health, and previous SAH[1]. $\mathrm{X_i}$ is a vector of time-invariant characteristics, including sex, race, years of education, and veteran status. ϵ_{it} is the random error term. In the second stage, r_i is the estimated retirement age obtained from the first stage.

1.3.2 Clustering on Individuals

The HRS collects data by interviewing each individual every two years; thus, there are multiple observations for each individual. Therefore, it is possible and necessary to cluster on individuals. The coefficients of clustered and unclustered regressions should be the same, but the standard errors can be different. The equations for unclustered and clustered variance estimators are as follows:

[1] HRS is implemented biennially, therefore previous mental and previous SAH were the data collected in the previous interview, two years ago.

$$(1.4)\ V = (X'X)^{-1} * \left[\sum_{i=1}^{N} (\varepsilon_i x_i)' * (\varepsilon_i x_i)\right] * (X'X)^{-1}$$

$$(1.5)\ V_{cluster} = (X'X)^{-1} * \sum_{j=1}^{J} \mu_j' * \mu_j * (X'X)^{-1},\ \mu_j = \sum_{jth\ cluster} \varepsilon_i x_i$$

For simplification purposes, the time subscription is dropped. ε_i is the error term for the i^{th} observation, and N is the total number of observations. μ_j is the within-cluster error term for the j^{th}cluster, and J is the total number of clusters ($J = 2{,}154$).

1.4 Results

1.4.1 Descriptive Statistics

The descriptive statistics are presented in Table 1.2. The average retirement age of the treatment group was 0.2 years higher than that of the control group, and the average CES-D score of the treatment group was 0.07 points lower than that of the control group. The other statistics of the treatment groups and the control groups were similar. The average age in both groups was just above 66 years. The overall race and gender composition of the two groups was almost identical. Wealth was calculated by adding up all the wealth components, including both housing and non-housing financial wealth, less all debt (RAND HRS Data Documentation, 2015). To reduce the influence of outliers and inflation, wealth was presented in the log of thousand dollars, adjusting for inflation. The average wealth value, education level, SAH, and marital status were very close in both groups.

Table 1. 2: Descriptive statistics

	Treatment group, born between 1938 and 1941				
	Mean	SD	Min	Max	N
Retirement age	63.54	1.41	62	66	1,237
CES-D	0.87	1.45	0	8	1,237
Age	66.56	2.28	62	70	1,237
Gender	1.52	0.50	1	2	1,237
Education years	12.70	2.60	0	17	1,237
Race	1.20	0.44	1	3	1,237
SAH	2.57	0.85	1	4	1,237
Veteran	0.24	0.43	0	1	1,237
Wealth (2010 USD)	5.30	1.61	-5.30	9.37	1,237
Marital	1.44	0.76	1	3	1,237
CESD_2	0.85	1.45	0	8	1,237
SAH_2	2.51	0.88	1	4	1,237
	Control group, born between 1928 and 1937				
	Mean	SD	Min	Max	N
Retirement age	63.32	1.34	62	66	3,111
CES-D	0.94	1.44	0	8	3,111
Age	66.50	2.36	62	70	3,111
Gender	1.48	0.50	1	2	3,111
Education years	12.50	2.87	0	17	3,111
Race	1.19	0.47	1	3	3,111
SAH	2.41	0.87	1	4	3,111
Veteran	0.33	0.47	0	1	3,111
Wealth (2010 USD)	5.31	1.61	-5.62	9.66	3,111
Marital	1.38	0.73	1	3	3,111
CESD_2	0.91	1.44	0	8	3,111
SAH_2	2.46	0.87	1	5	3,111

Note. Mental health and SAH becomes worse as the value increases. Gender=1 for males, and =0 otherwise. Race=1 for white, =2 for black, and =3 for others. Veteran=1 for veterans, and =0 otherwise. Wealth is in the log of thousand dollars, converting into a 2010-dollar value by utilizing historical CPI data in the US. Marital=1 if married or partnered, =2 if separated or divorced, =3 if widowed or never married.

1.4.2 Regression Results

1.4.2.1 OLS Estimation Results

The OLS results are shown in column (1) of Table 1. 3. The insignificant correlation between retirement age and mental health was in the range of $[0.003, 0.035]$. However, due to the endogeneity concerns discussed previously, this result is not compelling. Thus, the instrumental variable was utilized to identify the causal effect of retirement age on mental health.

1.4.2.2 IV Estimation Results

The first-stage estimation results (Column 2, Table 1. 3) demonstrate that the 1983 amendments raised the average retirement age, which is consistent with the conclusion in the literature. Specifically, for each year that an individual's birth year is later than 1937, the average retirement age increases 0.8 months at the 1% level. The results also suggest that people with an unhappy marriage relationship are more likely to retire later. A higher education level is also associated with a higher retirement age. It is not surprising to find that better self-assessed health conditions encourage people to retire later. However, wealth had no significant impact on retirement age, according to the first-stage estimation results. One explanation for this result is the endogeneity between the time of retirement and wealth. Certainly, people have more time to accumulate more wealth by receiving more working payments if they retire later. However, people with more wealth are more confident in retiring earlier because they have fewer financial concerns during their retirement life. Therefore, an insignificant coefficient of wealth in this regression is reasonable.

The IV estimation (Column 3, Table 1. 3) shows that, on average, retiring one month later reduced retirees' CES-D score by 1 point approximately, given a 95% confidence interval. As with other studies using an IV approach, what is reported by the IV estimation here is an average treatment effect; the most important thing is that the impact of retiring later on mental health is positive. Mental health also benefited from a better marriage relationship and a better SAH. Although more wealth did not significantly influence retirement age, more wealth did significantly promote mental health. The rationale for this result is straightforward, i.e., more wealth can relieve economic pressure on retirees. The results of the age fixed effects analysis indicate that aging plays a negative impact on mental health. An interesting finding is that current mental health is positively associated with previous mental health. This suggests that mental health outcomes build up over time.

Table 1. 3: Effect of postponing retirement on mental health

	OLS estimation (1)	1st stage estimation (2)	2nd stage estimation-Robust unclustered (3)	2nd stage estimation-Robust clustered (4)
	Mental health	Retirement age	Mental health	Mental health
Retirement age	0.019(0.016)	__	-0.769**(0.316)	-0.769*(0.396)
Z	__	0.063***(0.015)	__	__
Marital	0.183***(0.030)	0.103***(0.028)	0.267***(0.052)	0.267***(0.064)
Education	-0.042***(0.008)	0.045***(0.007)	-0.005(0.018)	-0.005(0.023)
Race	0.177***(0.047)	-0.079*(0.041)	0.114*(0.065)	0.114(0.081)
Gender	0.204***(0.054)	-0.079(0.050)	0.134*(0.073)	0.134(0.089)
Wealth	-0.032**(0.015)	-0.021(0.014)	-0.48**(0.021)	-0.48**(0.024)
SAH	0.272***(0.026)	0.045*(0.023)	0.242***(0.037)	0.242***(0.040)
Veteran	-0.010(0.058)	-0.129**(0.054)	-0.130(0.082)	-0.130(0.104)
CES-D_2	0.200***(0.015)	-0.002(0.014)	0.200***(0.022)	0.200***(0.023)
SAH_2	-0.053**(0.026)	0.093***(0.023)	0.022(0.044)	0.022(0.048)
F-statistic/Chi2	36.26	210.53	345.50	276.35
Age fixed	Yes	Yes	Yes	Yes
Observations	4,348	4,348	4,348	4,348

Note. Z = 0 if birth year<1938, =1 if birth year =1938, =2 if birth year=1939, =3 if birth year=1940, =4 if birth year=1941.
*p<0.1, **p<0.05, ***p<0.01

1.4.2.3 Comparison of Standard Errors

According to column (4) of Table 1. 3, the clustered standard errors were consistently larger than the unclustered standard errors. The sum of the correlations between the unobserved and the observed was more variable when the observations of the same individual over time were analyzed as a whole. That is, a positive correlation existed within each cluster. The positive correlation might, in part, emerge from mental health. The IV estimation has implied that previous mental health conditions have a lasting influence on current mental health. Therefore, the positive correlation among mental health outcomes for the same individual over time might increase the standard errors.

1.4.3 Robustness Checks

The above IV results are based on observations from respondents who were completely retired. However, as mandatory retirement has been abolished in many countries, many seniors who claimed themselves to be retired or had reached the benefit age were still working. To better reflect this reality, the current study analyzed the retirement age impact on mental health using an alternative sample that includes respondents who reported themselves as being retired but were still working. There are 6,341 observations in the alternative sample, with 1,873 observations in the treatment group and 4,468 observations in the control group. The IV estimation again supported the results that retiring later can significantly improve the mental health of seniors.

As a falsification test, this study investigated the retirement age impact on people who retired before age 62 or after age 66 using the same IV. If people did not retire in the regulated age range of 62-66, it suggests that the 1983 amendments were irrelevant to their retirement decision. As expected, retirement age had no impact on mental health using the current IV setting. A further IV regression was run against the sample that included people who retired earlier than age 62 or later than age 66. These results were biased by people who did not follow the 1983 amendments; therefore, the retirement age impact on mental health became insignificant.

More robustness checks were performed as follows. First, people who were younger than age 62 or older than age 70 were included in the samples. However, no observation younger than age 62 was found because the individuals needed to be retired and at no earlier than age 62 to ensure the validity of the instrumental variable. The result is robust, but the magnitude of the retirement age's impact was smaller. This outcome could be caused by measurement bias associated with the wider age range. Second, the study sample was extended to include people who retired between age 62 and age 70. The impact of retirement age on mental health remained because the 1983 amendments increased the benefits credit for those who retired later than the full retirement age but before age 70. Nevertheless, compared with that of the major results, this effect size was smaller. One possible explanation for this outcome is that part of the positive impact of postponing the retirement age was offset by the increasing age. Third, the control variables that did not have a statistically significant influence on mental health were dropped. Moreover, a matching estimation confirmed that the cohorts who were affected by the 1983 amendments had better mental health outcomes than those who were not affected on average. Overall, the causal effect of retiring later on mental health remained robust.

1.5 Discussions

The IV estimation found that people who were born after 1937 retired later since the inception of the Social Security Amendments of 1983, and the postponed retirement age had a positive impact on mental health. It is worth investigating further how mental health patterns differ among people who retired at different ages.

This study first examined the graphical evidence. Figure 1. 1 illustrates that the mental health of the control group was stable after retirement, while the mental health of the treatment group whose retirement age was postponed by the 1983 amendments was more variable. However, on average, as people had been retired for more years, those who retired later had a lower CES-D score, which reflects a better mental health condition.

Next, a mental health change variable was constructed. This variable is equal to 1 if the CES-D score is higher in the following period, which indicates a mental health deterioration; otherwise, the mental health change variable is equal to 0. Utilizing the same instrumental variable, an IV-Probit regression was run with the mental health change variable as the dependent variable clustering on individuals. The results suggest that retiring later reduced the likelihood of experiencing mental health deterioration (Table 1. 4).

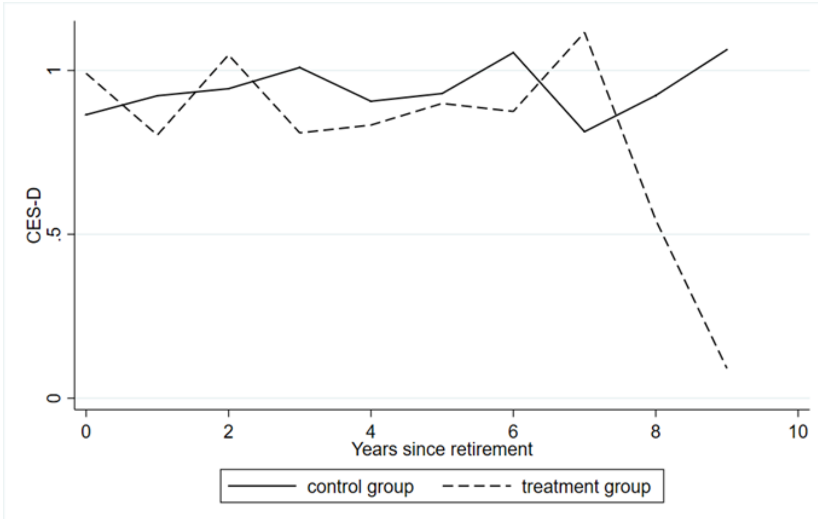

Figure 1. 1: Mental health since retirement

Table 1. 4: Likelihood of mental health deterioration

	IV-Probit regression
	Mental health change
Retirement age	-0.591***(0.122)
Z	__
Marital	0.105***(0.030)
Education	0.007(0.014)
Race	0.011(0.053)
Gender	0.072(0.070)
Wealth	-0.026*(0.015)
SAH	0.113**(0.046)
Veteran	-0.113*(0.062)
SAH_2	0.002(0.032)
Chi2	435.26
Age-fixed effects	Yes
Observations	4,348

Note. Mental health change=1 if worse off; =0 otherwise.
*p<0.1, **p<0.05, ***p<0.01

What are the potential mechanisms through which postponing retirement improves mental health? In the discussion that follows, three channels are proposed, namely, financial resources, social capital, and inherent personalities.

The first potential pathway is financial resources. Evidence of the positive correlation between financial situation and mental health dates back to the 1980s (Kahn, Wise, Kennedy, & Kawachi, 2000; Kessler & McRae JR., 1982). The Grossman model (1972) implies that if an individual has more money, then he or she will be able to invest more in health. As a result, health, particularly mental health, can be promoted. In general, a retired senior has two types of financial resources, namely, their inflow of income and their accumulated wealth. These two types work differently here.

A higher inflow of income provides some economic relief to the retirees, thereby improving mental health. If this is a mechanism through which retiring later promotes mental health, then people who retire later are expected to have a higher income during their retirement. That outcome is exactly what is presented in Figure 1. 2 (Panel A), i.e., the annual income from Social Security increased as the retirement age increased. One may wonder why that is. The answer has been given by Social Security policies. If an individual retires before the full retirement age, then his/her benefit will be cut accordingly until he/she reaches the full retirement age.

In contrast to the inflow of income, the relationship between accumulated wealth and retirement age is complex. On the surface, more accumulated wealth promotes mental health in the same way as a higher inflow of income does. Therefore, it is a valid pathway because later retirement means more time to save money. However, this argument can be criticized because people who accumulate more wealth are more confident in retiring earlier. The relationship between retirement age and accumulated wealth is contaminated by endogeneity. This argument explains why Figure

1. 2 (Panel B) does not report a consistent upward or downward trend in accumulated wealth as retirement age increases.

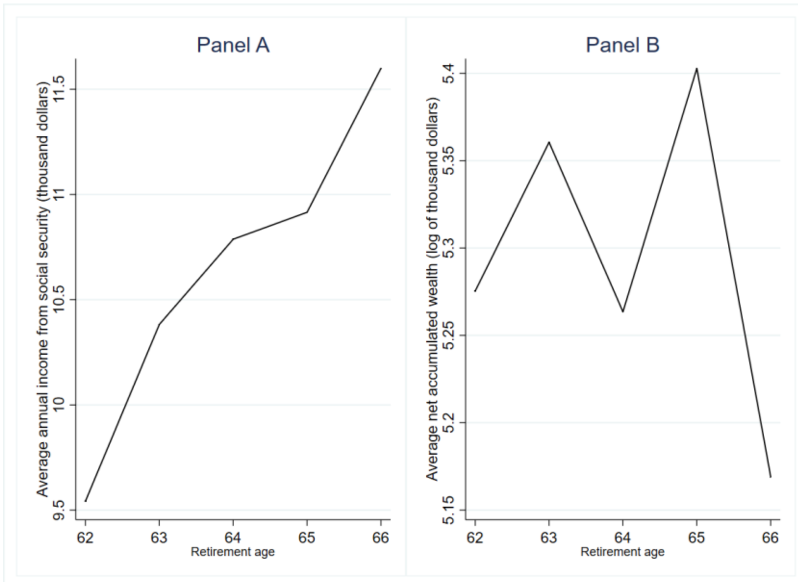

Figure 1. 2: Relationship between financial resources and retirement age

Table 1. 5: Financial resources and retirement age

	Annual income from social security	Accumulated wealth
Retirement age	5.401***(1.73)	-0.050(0.259)
Z	—	—
Marital	0.329(0.275)	-0.435***(0.046)
Education	-0.073(0.091)	0.182***(0.015)
Race	-0.340(0.312)	-0.636***(0.061)
Gender	-2.935***(0.382)	0.020(0.062)
SAH	0.205(0.0.179)	-0.153***(0.029)
Veteran	1.430***(0.463)	-0.038(0.070)
CES-D_2	-0.018(0.091)	-0.042**(0.017)
SAH_2	-0.902***(0.235)	-0.058(0.038)
Age fixed effects	Yes	Yes
Chi-square	1338.25	1004.57
Observations	4,348	4,348

Note. Annual income from social security is in thousand dollars. Accumulated wealth is in the log of thousand dollars. Both annual income from social security and accumulated wealth are converted into a 2010-dollar value by utilizing historical CPI data in the US.
*p<0.1, **p<0.05, ***p<0.01

In addition to the graphic evidence, the IV regressions were ran replacing the independent variables with income from social security and accumulated wealth. Table 1. 5 presents the results. Consistent with what was shown in Figure 1. 2, later retirement age is found to be significantly associated with a higher social security income, but it does not secure a higher level of accumulated wealth. That is, later retirement enhances mental health through a higher postretirement inflow of income, but not through accumulated wealth. More accumulated wealth could be good for mental health, but it is not a valid mechanism behind the retirement age effect.

Social capital is another possible pathway. Retirement is associated with massive lifestyle changes, and one of these changes occurs in social capital. “Social capital is a way of describing social relationships within societies or groups of people” (Silva, McKenzie, Harpham, & Huttly, 2005). Substantial literature has documented the positive connection between social capital and mental health (Calvo et al., 2013; Forsman, Herberts, Nyqvist, Wahlbeck, & Schierenbeck, 2013; McKenzie, Whitley, & Weich, 2002; Sahlgren, 2013; Silva et al., 2005). Retirement is particularly relevant to the loss of work-based social capital, which could hurt mental health. Retiring later might help to maintain the work-based social capital and give seniors more time to prepare for the life transition, which benefits their mental health.

There are several crucial difficulties with the analysis of this pathway. In particular, the social capital change before and after retirement is not possible to be detected given the current datasets. Additionally, work-based social capital is of interest, but it is difficult to distinguish work-based social capital from general social capital. Moreover, after retirement, people might invest more time in other types of social capital to compensate for their loss of work-based social capital. Being unable to measure the magnitude of this substitution effect is another difficulty. The endogeneity between social capital and retirement age also obstructs the analysis.

Table 1. 6: Likelihood of having friends

	IV-Probit regression
	Whether have friend
Retirement age	0.662***(0.077)
Z	__
Marital	-0.087(0.080)
Education	-0.064**(0.028)
Race	-0.044(0.126)
Gender	0.276(0.200)
Wealth	0.103*0.055)
SAH	0.131(0.110)
Veteran	0.271*(0.158)
CES-D_2	0.001(0.042)
SAH_2	-0.053(0.071)
Age fixed effects	Yes
Chi-square	344.78
Observations	517

Note. Whether have friend=1 if yes; =0 otherwise.
Only a portion of the respondents from RAND HRS longitudinal file was interviewed for the HRS Psychosocial and Lifestyle Questionnaires from 2006-2012. By merging the major sample with observations from the Psychosocial and Lifestyle Questionnaires, the finalized dataset is almost non-panel, so I treated this dataset as cross-sectional here.
*p<0.1, **p<0.05, ***p<0.01

If social capital is a valid mechanism, we should be able, to some extent, to show that retiring later enhances social capital. To overcome the endogeneity issue, retirement age was again instrumented with the Social Security Amendments of 1983. In addition to the HRS longitudinal file, data from the HRS Psychosocial and Lifestyle Questionnaires from 2006-2012[2] was utilized. The "social relationship" content in the complementary data source collected information on friends(Psychosocial and Lifestyle Questionnaires, public use dataset, 2006-2012), and the

[2] HRS Psychosocial and Lifestyle Questionnaires started in 2004. This paper used the 2006 – 2012 waves because the 2004 questionnaire was a pilot study that had different question designs.

concept of “friends” is widely adopted as a measurement of social capital. To avoid the complexity of distinguishing work-based friends from general friends, the variable describing “whether (the respondent has) any friends” was chosen as the dependent variable in the IV-Probit regression. The results in Table 1. 6 suggest that retiring later increases the likelihood of having friends.

In addition to work-based social capital, a spouse is a type of family-based social capital. The first-stage estimation results (Column 2, Table 1. 3) indicate that people who had worse marriage relationships or had no partners were more likely to retire later. Maybe these people had to work longer to financially support themselves because they had no partners to rely on. Or, there is less requirement to take care of a sick spouse for people who did not have a spouse, so they simply had more time to work. Another interpretation is these people invested more time in work-based social capital to compensate for the loss of family-based social capital.

The third possible pathway is the attitude toward work. Some people value work more than leisure (work lover) while others have the opposite preference (leisure lover). We can anticipate that later retirement improves the mental health of work lovers more than leisure lovers. Put negatively, later retirement can impair the mental health of leisure lovers. Our estimated retirement age effect on mental health was an average of the effects of work lovers and leisure lovers. We identified a significantly positive effect either because both types benefit from retiring later, to different extents, or because the positive effect on the work lovers dominates the ambiguous effect on the leisure lovers. Lacking relevant data to define the attitude toward work hinders an explicit empirical analysis of this mechanism at this time. However, this influence was reflected implicitly by the increased standard errors and the reduced confidence level of the effects of retirement age on mental health when clustering on individuals (Column 4, Table 1. 3).

This study has three potential limitations. First, the CES-D is designed to measure depression, but depression is only a narrow view of mental health disorders. Regarding this limitation, the HRS team defended themselves by claiming that depression is the most common psychiatric disorder among elderly individuals and therefore, the HRS team chose to focus on this measure in particular (Steffick, 2000, p.3). Among the various depressive indicators used in psychiatric and psychological research, the CES-D was chosen because its use is widespread. Moreover, the CES-D and many other indicators use similar questions (Steffick, 2000, p. 4). The CES-D has also been utilized extensively by the literature focusing on mental health (Dave et al., 2008; Lindeboom, Portrait, & Berg, 2002; Steffick, 2000). From this point of view, the CES-D is not perfect, but it fits this research. Second, it is not possible to control for all the other policy changes or events, for example, other Social Security reforms, Medicare, World War II, etc. However, the IV approach herein essentially compared the mental health difference that was induced by retirement age between the treatment group and the control group. Thus, only changes that particularly affected one of these two groups might significantly affect the results. All Americans above age 65 are eligible for Medicare, the US entered World War II on December 07, 1941, which is the end of the year in which the youngest cohort in this research sample was born, and a further review of US Social Security policies did not find other changes that could considerably affect the conclusion of this paper. Regarding World War II, both the direct exposure and the formative shocks, e.g. unemployment, poor nutrition, and the turbulent social environment, might affect mental health. But it should not cause serious concern for two reasons. First, the war would affect both the control and treatment groups. As discussed previously, such an event does not violate the validity of the IV. Second, people in the treatment group were born between 1938 and 1941, and only a small portion of people in this group was born after the US entered the war. This small portion of people might have worse mental health conditions in their later lives because the shocks following the war might adversely affect mental health. In other words, the shocks could lead to a downward bias of the estimated impact of later retirement age on mental health. Given that the IV estimation of such impact is still positive, despite the potential downward bias, the conclusion of the positive impact of retiring later on mental health is robust. Additionally, the literature assessing the health and economic outcomes of social security reforms involving the 1983 amendments did not report concerns about the war or other events. For instance, Duggan (2007), Mastrobuoni (2009), Blau and Goodstein (2010), Goldman, etc. (2013), Zissimopoulos, etc. (2017). Therefore, the potential impact of these items should be minor. Lastly, the attitude toward work cannot be empirically analyzed due to lack of available data. No data in the dataset can be utilized to define work lovers or leisure lovers. It will be helpful to include a sophisticated experiment exploring the attitude toward work in future research.

1.6 Conclusions

This study found that retiring later has a modest positive effect on mental health. It should be highlighted, however, that in this study setting, the retirement age was raised gradually and slightly. The Social Security Amendments of 1983 were designed to raise the benefit age by two months each year, and this change was announced to the public well in advance. These facts are crucial because it takes time for people to adapt to policy changes and subsequent life changes. If a change is massive and unexpected, then its effect on mental health might be uncertain.

Our results showed that mental health builds up over time. Previous mental health has a significant impact on current mental health. This empirical evidence thus implies that, similar to how it requires effort to build and maintain physical health, so it is with mental health. Furthermore, self-assessed health (SAH) and mental health are closely linked. A better SAH was found to be associated with better mental health status.

In general, this study implied that policies aimed at raising the retirement age may not only address the financial difficulties of social security systems but may also ameliorate the retirees' mental health. Given the lack of discussion on such mechanisms in the literature, this study provided three possible pathways through which retiring later improved mental health. Future studies could consider constructing a formal theoretical model to incorporate these pathways and better motivate empirical works in this area.

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Chapter 2

Peer Effect on Dairy Farmers' Willingness to Accept, Use, and Pay for a Johne's Disease Vaccine

2.1 Introduction

Peers[3] or neighbors can be especially influential in the Canadian dairy industry because the Supply Management (SM) eliminates the competition between dairy farmers and fosters a united community for them. On the other hand, information transmission in and out of this community is not as transparent as the outside. It is challenging to predict if and how peers can affect Canadian dairy farmers' management decisions. This research aims at explaining and evaluating the peer effect on Canadian dairy farmers' decisions regarding the uptake of a vaccine against Johne's disease (JD).

Dairy farmers' decisions on the applications of biotechnologies, such as vaccination, affect not only the animals' wellbeing and farm profitability, but also the dairy industry's performance. In Canada, taking advantage of SM, production of each farm, price paid to the farmers, and the dairy products imports are predetermined by the national marketing agency and provincial marketing boards. Rather than competing with peers, Canadian dairy farmers maintain the community's reputation as a team. Fewer disease outbreaks and lower disease prevalence is the collective objective of the whole community. In addition to the cooperative relationship among the farmers, multiple surveys of farmers have implied that dairy farmers consider peers as a reliable information source (Alarcon, Wieland, Mateus, & Dewberry, 2014). It is reasonable to argue that peer farmers'

[3] For simplification, in the following sections, peer stands for both peer and neighbors, peer effect represent both peer effect and neighbor effect.

actions can significantly affect farmers' decisions. If so, professionals working in this industry may want to adjust the strategies of vaccine delivery and disease controls accordingly.

Johne's disease (JD) is a chronic, infectious bovine disease, and there is no cure for it. The infected animals will experience progressive weight loss, diarrhea, and eventually die. Substantial evidence suggests that JD causes significant economic losses due to reduced milk production, culling, and animal replacement costs (Chi, VanLeeuwen, Weersink, & Keefe, 2002; Raizman et al., 2006). Nevertheless, some dairy industry reports showed that the participation rate of voluntary JD control programs in Canada was low, and dairy farmers' commitment to execute control strategies was sluggish (Raizman et al., 2006; Ritter et al., 2015; Sorge et al., 2010). Dairy farmers' hesitation in controlling for JD together with the unique characteristic of Canadian dairy farmers' community provides an appropriate opportunity to investigate whether and how peers' actions can influence dairy farmers' willingness to accept, use, and pay for a JD vaccine.

2.2 Literature Review

According to the literature, this paper summarizes peer effect as the effect that is incurred by the interaction between individuals within a specific community or network (Dupas, 2014; Jones, Evangelions, Halvadakis, Losifides, & Sophoulis, 2010; Kwon & Jun, 2015; Plott & Zeiler, 2005; Zhang, Wang, Wang, & Hsiao, 2006). In this paper, peer effect means that a dairy farmer may or may not be more willing to accept, use, and pay for a JD vaccine when his or her peers' actions are provided to them.

In the literature, peer effect is also known as the effect of social capital. Social capital is defined as social networks, which act as information resources for decision makers (Coffman, Featherstone, & Kessler, 2017; Zhang et al., 2006). Zhang et al. (2006) considered social capital as a combination of trust and reciprocity. They collected social capital data by distributing a questionnaire to residents living in a Chinese village which included specific questions to construct a trust index and a reciprocity index. All these questions are designed according to guidelines provided by the World Bank. The trust index measures how individuals trust in their social networks. For example, one question asked "Do you think the village leaders can be trusted?" (Zhang et al., 2006). The reciprocity index evaluates the cooperation in the community. One of the reciprocity related questions was "Would you like to support a project that might not benefit you the most but benefit other villagers?" (Zhang et al., 2006). As an extension to the work by Zhang et al. (2006), Polyzou (2011) measured social capital with four components: social trust; institutional trust; social networks and civic participation; and compliance with social norms. Most literature focused on social capital shared the similar logic that after receiving the information from their social networks, people might ask themselves, "should I take the same action based on the information I received?". Following this logic, the dairy farmers might ask themselves, "should I follow my peers to accept or refuse the JD vaccine?".

Other studies have illustrated the peer effect as the effect of information spillover (Barnhardt, Field, & Pande, 2017; Dupas, 2014; Gowrisankaran & Stavins, 2004). Dupas (2014) interpreted that information spillover can have an effect on a household's decision about a product because people can get a signal about that product's quality. After one household adopted the product, the household members would distribute the product's information among their social networks. Another household that received the information would update their perception of the product, and then decide whether to adopt or not. The empirical results of Dupas's study concluded a positive information spillover effect (Dupas, 2014). That is, the households were more likely to follow their neighbors if they received positive feedback from them. The belief update process described by Dupas is a realistic example of how peers can work in the vaccine adoption situation: the dairy farmers can update their belief in the JD vaccine after knowing their peers accept or reject the JD vaccine.

Essentially, the abovementioned studies consider peers as a type of information source. Kandel and Lazear (1992) provided a theoretic framework showing how peer pressure encourages more efforts from workers in a partnership. They proved theoretically that efforts made by peers in the same network impose pressures on individuals. The pressures trigger the feelings of guilt and shame, therefore, drive the individuals to pay more efforts. In 2005, Kwon and Jun applied peer effect to look into doctors' decisions on antibiotics prescription. They explained that social pressures could make doctors prescribe fewer antibiotics because it is the socially "right" thing (Kwon & Jun, 2015). The authors empirically showed that a policy that mandatorily publishing antibiotics prescription rate online reduced the unnecessary prescription rate significantly.

Peer effect has been well recognized in the agriculture sectors. Ward and Pede demonstrated that nearby hybrid rice adopters promoted the cultivation of hybrid rice in Bangladesh (Ward & Pede, 2015). When promoting a new farming practice, the neighbor effect was proven to be a significant determinant (Tessema, Asafu-Adjaye, Kassie, & Mallawaarachchi, 2016). Lynham (2017) found that when choosing where to fish, peers' location choice was strongly influential on the new entrants (Lynham, 2017).

There is a rich literature focusing on the positive peer effect - individuals are more likely to imitate the actions from their peers. The opposite possibilities of peer effect have not been widely discussed (*e.g.*, the classic free-rider problem). However, it is indispensable in this present study because JD is an infectious disease. When some dairy farmers vaccine their animals, the risk of JD is not only reduced on their own farms but also in their neighborhood. As a result, the other farmers are able to save some of the efforts. In addition, limited literature provided both theoretic and empirical analysis of peer effect.

Taking advantage of a new-developed JD vaccine distribution scenario, this study aims to extend the literature by modeling Canadian dairy farmers' behaviors on animal health management, illustrating both positive and negative peer effects. The behaviors of dairy farmers under the supply management system are analyzed with a theoretical model first. To examine the theoretical conclusions, an experiment was implemented among Canadian dairy farmers. The data collected from the pilot experiment positively supports the theoretical conclusions.

2.3 Theoretical Framework

2.3.1 Competitor or Partner?

The Canadian dairy industry does not meet the qualifications for a perfect competition market or an imperfect competition market. The conditions for a perfectly competitive market are listed slightly differently by different authors, including (Hayek, 1948; Mankiw, Kneebone, & McKenzie, 2017; Mas-Colell, Whinston, & Green, 1995). Here we follow the three conditions generalized by Hayek in 1948: "1. A homogeneous commodity offered and demanded by a large number of relatively small sellers or buyers, none of whom expects to exercise by his action a perceptible influence on price. 2. Free entry into the market and the absence of other restraints on the movement of prices and resources. 3. Complete knowledge of the relevant factors on the part of all participants in the market." (Hayek, 1948). On the surface, condition 1 is satisfied. However, it is the supply management system that takes away market power from the dairy farmers, not the competition. Speaking of free entry, although new entry is not ruled out officially, the expensive and limited amount of dairy quota acts as a barrier to entry. Thirdly, the decision process under the supply management system is complicated to understand for dairy farmers, and it limits the information circulated. In the first place, the price paid to the farmers and the quantity of milk production in Canada is predetermined by the Canadian Dairy Commission (Canadian Dairy Commission, 2018). In addition, because the price and quantity are not the results of the market, dairy farmers lose the opportunity to understand the demand side, such as the actual quantity demanded by the consumers, consumers' tastes and preferences for milk, etc. Similarly, it is almost impossible for consumers to convey a message directly to individual farmers. As mentioned above, in the Canadian dairy industry, there lack basic qualities for a perfectly competitive market.

Moreover, a proposition of monopolistic competition is problematic because some important conditions are absent. Monopolistic competition requires that producers have some market power to impact the price because the products they are selling are somehow differentiated from their competitors. However, it is illogical to claim that the major products that dairy farmers produce, mostly milk, are different from one another. Meanwhile, Canadian dairy farmers are paid with a preset price, no single farmer is able to influence the price.

Indeed, Canadian dairy farmers are not competing with each other. The supply management system effectively mandates that quota be assigned to dairy farms, sets the milk prices, and restricts pressure from international trade. As a result, dairy farmers are not able to and do not need to compete for a larger market share, nor a higher price. "…dairy and poultry farmers do not feel like competing with anyone" (Morris, June 21, 2018). In addition, as supply management is facing challenges, both domestic and international, Canadian dairy farmers and their lobbies defend this protective system unitedly. The dairy farmers work collaboratively in order to make the herds healthy. The lobbies representing dairy farmers are dedicated to a good industry reputation. Encouraging farmers to work toward animal health is one important objective for the lobbies. The supply management system allows farmers to receive a good price of milk, which in turn allows farmers to invest in animal health. Thus, the dairy lobbies will argue that supply management encourages excellent animal health.

Therefore, it is reasonable to assume that rather than competing, Canadian dairy farmers are in a partnership relationship where they share a stable revenue under supply management. As the Dairy Farmers of Canada stated, the Canadian dairy farmers are "looking after one another. Driven by teamwork, integrity, and passion" (Dairy Farmers of Canada, 2019). After sweeping away the confusion of competition, we are able to apply Kandel and Lazer's theoretical work on peer pressure and partnerships in 1992 to explain why peers' behaviors matter and why we could observe free-riding.

2.3.2 Free Riders

In the same partnership, the Canadian dairy farmers have one thing important to share: the reputation of the industry. To do so, they work collaboratively to keep their animals healthy. However, it does not mean the dairy farmers' team spirit can eliminate free-riding. In the following section, we explain why some dairy farmers pay fewer efforts than their peers.

Suppose a dairy farmer pays effort e to achieve a specific output. Certainly, the output shared by the dairy farmers can also refer to the industry's reputation, or the total milk production. But this paper is interested to know the farmers' decision on an animal disease vaccine; thus, animal health (h) of the overall industry, is chosen to be the output. Taking health as an output is not initiated by us; the Grossman model (1972) and other types of health production models have been widely applied in human health research.

As the output of interest in this present study, the industry animal health is a function of farmers' efforts, $\mathrm{h} = \mathrm{h(E)}$, $h' > 0, h'' < 0$. There are N identical dairy farmers in the industry, so $E = [e_1, e_2, \dots, e_n]$. A particular farmer's hard work might improve his own herd's health, but the industry's animal health condition depends on all the farmers' work. Therefore, $h(E)$ is assumed to be non-separable in e_i. The farmers will have to pay some cost, C, when making effort, and farmer $i's$ cost is a convex function of his/her efforts, $C = C(e_i)$, where $C' > 0$, and $C'' > 0$. As long as $N > 1$, free-riding occurs:

Farmer $i's$ objective function is: $max_{e_i} \frac{h(E)}{N} - C(e_i)$.

First order condition is: $\frac{h_i(E)}{N} - C'(e_i) = 0$.

Each dairy farmer's optimal effort level is e'.

For the whole industry, the objective function is: $max_{e1,e2,...,eN}\ h(E) - \sum_{i=1}^{N} C(e_i)$

The optimal level effort of each identical farmer, e^*, would be derived from $h'(E) - C'(e_i) = 0$. Given the convexity of the cost function, $e^* > e'$. That is, the dairy farmers might take advantage of their peers' effort. Johne's disease is an infectious disease. One farmer's effort of reducing the risk of JD generates positive externalities. This enables dairy farmers to work less hard but enjoy good animal health conditions.

2.3.3 Farm Size Matters

Assuming each dairy farmer earns the same share of the output might not be realistic. The Canadian dairy herd is comprised of herds of different sizes. A larger herd accounts for a larger part of the Canadian herd. The animal disease control strategy chosen by larger farm operators is more influential on the overall animal health of the industry compared with the smaller farm operators. Moreover, the impact of the same infectious disease is bigger on larger farms than the smaller farms simply due to more animals being present on larger farms. All in all, farmers who manage larger herds claim a larger share of the total output, animal health.

Therefore, we extend the Kandel and Lazear's model by assuming that output is distributed to dairy farmers based on the herd size. The individual farmer's objective function becomes:

$$max_{e_i} h(E) * s_i - C(e_i)$$

Where $s_i = \frac{animal\ number\ in\ farm\ i}{total\ animal\ number\ in\ Canada}, 0 < s_i < 1, \sum_{i=1}^{n} s_i = 1$. s_i is a constant number because the number of animals on a farm is mainly determined by the production quota a farm owns, and total production quota is almost fixed. An increase in the overall productivity could reduce the total number of animals in the industry, as well as the number of animals in the individual farm, thus the share s_i remains the same. The first order condition is: $h'_i(E) * s_i - C'(e_i) = 0$, and we can solve for e^{s_i} from there.

Suppose there are two dairy farmers with efforts level of e_1 and e_2, output shares of s^1 and s^2, $s^1 > s^2$. That means: $h'_1(E) * s_1 - C'(e_1) = h'_2(E) * s_2 - C'(e_2) = 0$. Therefore, we have:

$$\frac{h'_1(E)}{C'(e_1)} < \frac{h'_2(E)}{C'(e_2)}$$

Given the convexity of the cost function and the concavity of the production function, $e_1 > e_2$, $\frac{\partial e}{\partial s} > 0$. As s is larger, the effort level is higher. That is to say, a farmer running a farm with more animals is willing to pay more efforts on animal health, and he/she would be more willing to use the vaccine. The larger farm owners do so to protect their greater share of the total animal health. With supply management system, both aggregate and individual production quota are considered to be fixed, therefore the sizes of both small and large farms are unlikely to change unless someone withdraws. That means small farms stay small, and they always have a weaker impact on the industry. The smaller share of output and the limited influence over the industry discourage the smaller farm owners, that is why they might pay fewer efforts to maintain the industry's wellbeing[4]. The positive relationship between effort level and the output level also suggests the following:

$e^{s_i} > e'$, if $s_i > \frac{1}{N}$;

$e^{s_i} = e'$, if $s_i = \frac{1}{N}$;

$e^{s_i} < e'$, if $s_i < \frac{1}{N}$.

The next question is: is it possible that a farm is large enough to drive the owner to pay the optimal level of effort, e^*, or even more than that?

The first order condition solving for e^* is $h'(E) - C'(e^*) = 0$; the first order condition solving for e^s is $h'(E) * s - C'(e^s) = 0$. So, $\frac{h'(E^*)}{C'(e^*)} = \frac{h'(E^S)}{C'(e^S)} * s$. For simplification, the subscript i of s is dropped from now.

If $e^* = e^s$, we need $s = 1$ to make the above two first order conditions valid at the same time. If $e^* < e^s$, we have $\frac{h'(E^*)}{C'(e^*)} > \frac{h'(E^S)}{C'(e^S)} * s$. Again, the above two equations cannot be true simultaneously. The only feasible solution is $e^* > e^s$.

Dairy farmers' effort level differs along the farm sizes. Smaller farm owners would pay even fewer efforts compared with the scenario when output is evenly distributed among farmers. The positive externalities generated by their peers' efforts make it possible for them to take a free ride. Larger farm owners work harder, but their effort level does not match the optimal level because the resulting animal health cannot be privatized.

[4] The argument here is smaller farmers might pay less efforts, but it does not mean that smaller farmers favor the supply management system less. Indeed, limited by the farm size, economic scale can be hardly achieved. Once the protection from SM is gone, surviving the competition could be a tougher issue for the smaller farmers.

2.3.4 Peer Pressure

If free-riding is possible, why does the hard work of peers matter? Although it is not the whole story, peer pressure can help to explain it. Define peer pressure function as:

$$P = P(e_i; a_i)$$

Different from the original model, here a_i is the efforts taken by farmer $i's$ peers rather than the other actions taken by farmer i, such as monitoring other farmers' efforts. This is to adapt the model to the dairy industry. Unlike in a typical firm or factory, co-workers are working at the same workplace and it is convenient to monitor their peers' efforts. For most of the time, dairy farmers are working on their own farms. Occasionally observing what their peers are doing is possible, but it is not practical to monitor peers. However, it remains useful and reasonable to point that although peer pressure is a type of cost to the dairy farmers, the nature of $P(.)$ is social (Kandel & Lazear, 1992), and it originates from dairy farmers' interactions.

There are two types of peer pressures: internal peer pressure and external peer pressure. The farmer's objective function is:

$$max_{e_i} h(E) * s - C(e_i) - P(e_i, a_i)$$

Internal peer pressure means $\frac{\partial P}{\partial e_i} < 0$, and external peer pressure is revealed as $\frac{\partial P}{\partial a_i} > 0$. Paying more efforts makes a farmer feel less guilt, thus less internal peer pressure; peers' higher level of efforts impose more external peer pressure on a farmer and he/she could suffer from the feeling of shame.

We start from the internal pressure and ignore the external peer pressure for now. The first order condition is: $h'_i(E) * s - C'(e_i) - P'_{e_i} = 0$. The resulting effort level is e^P. We have:

$$h'(E^P) * s - C'(E_i^P) - P'_{e_i^P} = h'(E^S) * s - C'(E_i^S) = 0.$$

Suppose $e^s > e^P$, then $C'(e^s) > C'(e^P)$ as $C'' > 0$. Then $h'(E^P) * s - P'_{e_i^P} < h'(E^s) * s$. Since $\frac{\partial P}{\partial e_i} < 0$, $h'(E^P) < h'(E^s)$. However, this violates the feature that h is a concave function of effort. Therefore, $e^P > e^s$, internal peer pressure encourages dairy farmers to pay more effort on animal health.

The crucial assumption enables us to conclude $e^P > e^s$ without uncertainty is $\frac{\partial P}{\partial e_i} < 0$. But does it mean a dairy farmer does not feel guilty only if his/her effort tends to be extremely large? It does not sound realistic. The external peer pressure answers this question. We modify the dairy farmers' objective function further:

$$max_{e_i} h(E) * s - C(e_i) - P(a_i - e_i)$$

If $a_i \leq e_i$, $P = 0$, and $P' = 0, P'' = 0$; otherwise $P > 0$, and $\frac{\partial P}{\partial (a_i - e_i)} > 0$, $\frac{\partial P}{\partial a_i} > 0$, $\frac{\partial P}{\partial e_i} < 0$. In addition, as the effort difference between farmer i and his/her peers, $a_i - e_i > 0$, is increasing, farmer i feels more pressure, $\frac{d^2 P}{d(a_i - e_i)^2} > 0$. It should be noted that a_i refers to the peers that farmer i cares about and is able to know their efforts rather than all the other farmers in the industry. Kandel and Lazear argued that farmers care about some peers more than others because of empathy (Kandel & Lazear, 1992). In the case of this study, Alberta farmers might not value the Quebec farmers' opinions as important as their closer neighbors'. Moreover, we believe that the other influencing factor is information – knowing everyone else's effort in the industry is impractical. Obviously, it is difficult for Alberta dairy farmers to know exactly what Quebec farmers do and how they do it.

The asymmetric information not only restricts a_i to a limited circle but also reduces the power of peer pressure. To see this, consider the cost of the peer pressure as the probability of a farmer being caught by his/her peers that he/she is lazy, and that being caught results in a certain amount of penalty. Obviously, a world with perfect information would make the chance of being caught so high that all the farmers would work at least as hard as their peers. Then the remaining task for a social planner is to calculate the amount of penalty to overwhelm the cost saved from negligence. Because we are not living in a world with perfect information, an external monitoring system could compensate for the lack of information on peers' efforts and therefore improve farmers' effort level. However, there seems to be no such powerful and proper policy.

2.3.5 The Penalty

Peer pressure can improve the effort level, but it is not sufficient to drive the effort to the optimal level. Under the supply management system without a proper policy aiming at optimizing the farmers' efforts on animal health, it is difficult to convince farmers to try their best to control for various animal diseases. If efforts on animal health are voluntary, how do dairy farmers allocate their control efforts among different diseases? The penalty associated with the disease serves the end.

When it comes to animal disease, less effort increases the risk of disease. Therefore, even without external monitoring, losses associated with diseases enter the farmers' objective equation as penalties:

$$max_{e_i} h(E) * s - C(e_i) - P(e_i) - r(e_i)$$

where $r(e_i)$ represents the penalty imposed on the farmers if their animals are infected, $\frac{\partial r}{\partial e} < 0$. To reduce the disease risk to zero, everyone in the industry needs to work at their optimal level of effort, $r(e_i)|_{e_i \geq e^* \; and \; e_{-i} \geq e^*} = 0$. Once the effort level of each farmer in the industry reaches the optimal level, the additional effort has no impact on the penalty: if $E^r = E^*$, $r = 0, r' = 0, and \; r'' = 0$. First order conditions suggest:

$$h'(E^r) * s - C'(e^r) - P'(e^r) - r'(e^r) = h'(E^P) * s - C'(e^P) - P'(e^P) = 0$$

$$h'(E^r) * s - C'(e^r) - P'(e^r) < h'(E^P) * s - C'(e^P) - P'(e^P)$$

Note: $\frac{d^2P}{de^2} = \frac{d^2P}{d(a-e)^2} * \left(\frac{d(a-e)}{de}\right)^2 + \frac{dP}{d(a-e)} * \frac{d^2(a-e)}{de^2} = positive * (-1)^2 + positive * 0 > 0.$

Suppose $e^r \leq e^P$, then $h'(e^r) * s - C'(e^r) \geq h'(e^P) * s - C'(e^P)$. Because $\frac{d^2P}{de^2} > 0$, we have $P'(e^r) \leq P'(e^P) < 0$. So $h'(E^r) * s - C'(e^r) - P'(e^r) \geq h'(E^P) * s - C'(e^P) - P'(e^P)$, which violates what the first order conditions imply. Therefore, $e^r > e^P$, the penalty associated with the disease forces farmers to have to pay some efforts on animal health maintenance. The more penalty a disease can impose, the more effort a dairy farmer will pay, up to the market value of the dairy cows. To see this, consider an extreme situation where the penalty is zero even all the cows are infected with a disease. Then the effort level will reduce from e^r to e^p. Thus, dairy farmers facing various animal diseases will choose to focus on the diseases which would cause more visible losses.

By now, we have shown that $e^* > e'$, while the relationship between e' and e^s depends on whether the farm size is above the average farm size. After introducing peer pressure and disease penalty, we show that $e^r > e^P > e^s$. Lastly, we want to know if, driven by peer pressure and penalties associated with diseases, a dairy farmer will pay the optimal effort level regardless of farm size. Can we achieve the ideal situation where everyone works equally hard, and there is no free-rider issue?

In reality, there is no answer to the question that how much effort is enough to eliminate any animal health disease. It is normal that the productivity of a cow is lower when the cow occasionally gets sick. The cost associated with those “normal” health variations is not the focus here. Rather, we are interested in the animal health risks which could potentially cause disease outbreak and significant economic losses.

Recall that if all the farmers in the industry work at the optimal level of effort to control for a disease, then the individual farmer's risk of this disease is zero. The social planner's first order condition is: $h'(E) - C'(e_i) = 0$, and the individual's first order condition with peer pressure and disease penalty is: $h'(E^r) * s - C'(e^r) - P'(e^r) - r'(e^r) = 0$. We want to know whether $e^r = e^*$ for all dairy farmers is possible. It requires:

$$h'(E^r) * s - C'(e^r) - P'(e^r) - r'(e^r) = h'(E^*) - C'(e^*)$$

Substitute $e^r = e^*$ into the above equation:

$$h'(E^r) * s - C'(e^r) - P'(e^r) - r'(e^r) = h'(E^r) - C'(e^r)$$

So,

$$-P'(e^*) - r'(e^*) = h'(E^*) * (1 - s)$$

It cannot be held because when $a_i = e_i$, $P' = 0$ and $r'(e_i)|_{e_i \geq e^* \; and \; e_{-i} \geq e^*} = 0$, but $h'(e^r) * (1 - s) > 0$. That is, although peer pressure and penalty associated with diseases could improve the level of efforts, they are unable to lead the effort level to the optimal level.

We have shown that it is unlikely that everyone in the industry would pay the optimal effort level on animal health to eliminate diseases in the industry. But is it possible that an individual farmer works extremely hard to make sure that his/own farm is free of any disease? A more general objective function for a dairy farmer is to maximize the profit π by choosing the effort level e_i on animal health and the inputs o_i:

$$\max_{\{e_i, o_i\}} \pi = \bar{p} * \bar{y} - C_{health}(e_i) - C_o$$

The effort paid to maintain animal health generates cost, C_{health}, and other inputs are associated with cost, C_o. The output level is fixed by quota, and the price paid to the farmer is exogenously determined. Therefore, the revenue a dairy farmer can earn is fixed at the level of $\bar{p} * \bar{y}$. Assume other things constant, a farmer who tries his/her best to make the animals healthy might be able to produce the same amount of milk with fewer cows, but it does not affect his/her revenue. Meanwhile, his/her tremendous level of effort on animal health increases C_{health} significantly. Two conditions have to be satisfied in order to generate the incentive for a farmer to pay the high level of effort to eliminate any disease. First, the effort paid to eliminate diseases can reduce other costs, C_o; second, $|\Delta C_o| - |\Delta C_{health}| > 0$. The dairy farmer has to balance the significant cost increase in controlling for animal diseases and the ambiguous cost reduction in other inputs. When deciding whether to pay the high level of effort, the dairy farmer faces the uncertainty of whether or not these two conditions can be met. The uncertainty would make the dairy farmer hesitant about paying the high level of effort on animal health.

Peer pressure works from both internal pressure and external pressure. Internal peer pressure encourages farmers to work, and the external peer pressure sets the maximum level of effort to not fewer than the peers a farmer cares about. Peer pressure keeps the dairy farmers working on herd health collaboratively. This is because whether their preferable supply management system can survive depends, in part, by how the farmers maintain the industry' reputation; good animal health is useful to build up a good reputation.

Information asymmetry hinders the peer pressure from obtaining its best effect in improving farmers' effort level. In addition, it restricts the conception of "peers" to a smaller network. Without additional external policies to monitor farmers' efforts and impose punishment, the free-rider issue and fewer efforts will remain in the industry. Yet, the potential losses associated with disease offsets some of the free-riding effect. The penalty imposed by disease forces farmers to work, but farmers would focus on those diseases that could bring severer losses.

2.4 The Experiment

An experiment was implemented to examine the theoretical conclusions. In particular, we designed a questionnaire to explore whether Canadian dairy farmers' effort level on Johne's disease control is affected by peers, and whether the farmers accept or reject peers' action. Eventually, we aim to distribute the questionnaire across Canada and generate a representative sample for the entire Canadian dairy farmer community. At this stage, we first implemented a pilot project in Alberta, Saskatchewan, Manitoba, Quebec, and Ontario. These provinces were selected because they account for a large part of the Canadian dairy industry (Table 2. 1).

Table 2. 1: Dairy farms in Canada

Province	# of Farm	% of Canadian	# of cows	% of Canadian
SK	162	1%	29,000	3%
MB	277	3%	40,200	4%
AB	517	5%	81,200	8%
ON	3,534	33%	319,100	34%
QC	5,120	48%	357,200	37%
Total	9,610	90%	826,700	86%

Source: Canadian Dairy Information Centre: http://www.dairyinfo.gc.ca/index_e.php?s1=dff-fcil&s2=farm-ferme&s3=nb

2.4.1 Questionnaire Design

The questionnaire collected the following information for analysis: the dairy farmers' willingness to accept and use the vaccine; the prices that dairy farmers were willing to pay for the vaccine compared with the vaccines they were using; the dairy farmers' experience and knowledge of JD; the dairy farmers' information sources regarding farm management; and the dairy farmers' demographic information, such as education level, farming experience, and age. The questionnaire was hosted at the Social Science Research Laboratory at the University of Saskatchewan. This allowed anonymous participant implementation through an internet connection.

2.4.1.1 Assignment of the Participants

By assumption, a typical farmer's decision process about a JD vaccine consists of three stages: (1) The willingness to accept (WTA) the vaccine as a valid control option; (2) The willingness to use (WTU) the vaccine; (3) The willingness to pay (WTP) for the vaccine. The questionnaire introduced the peers' actions at the first two stages. Based on the timing of introducing the peers' actions, the participating farmers were divided into two groups.

In Group 1, the peers' action was introduced after the farmer makes an initial decision. If the initial decision is "yes", we ask "what if your peers do not accept, and use the vaccine?"; if the initial decision is "no", we ask "what if your peers accept, and use the vaccine?". In Group 2, the peers' action was introduced before an initial decision: some dairy farmers were told that their peers accept, and use the vaccine, while the other dairy farmers were told about the opposite information. Therefore, before the farmers reached the willingness to pay stage, depending on which group they are in, they were asked to make decisions about the vaccine corresponding to at least one of the four peers' actions: (1) The farmer decided before knowing the peers were willing to accept the vaccine; (2) The farmer decided before knowing the peers were unwilling to accept the vaccine; (3) The farmer decided after knowing the peers were willing to accept the vaccine; (4) The farmer decided after knowing the peers were unwilling to accept the vaccine. Figure 2. 1 and Figure 2. 2 illustrate the detailed logic map.

2.4.1.2 Scenarios Based on the Disease Prevalence Level and the Vaccine Efficacy

The other two considerable factors that would affect dairy farmers' attitude toward the JD vaccine are the prevalence of JD, and vaccine efficacy. To simplify, a highly effective JD vaccine is assumed[5]. Prevalence of JD measures the proportion of JD-positive cows in a given herd at a particular time, and it suggests the disease severity. The three scenarios based on the prevalence of JD are: Scenario 1: Suppose there is a highly effective vaccine against Johne's disease, and the herd level occurrence of Johne's is low in your province; Scenario 2: Suppose there is a highly effective vaccine against Johne's disease, herd-level occurrence of Johne's is moderate in your province; Scenario 3: Suppose there is a highly effective vaccine against Johne's disease, herd-level occurrence of Johne's is high in your province. Participating farmers were first randomized into either Group 1 or Group 2. They were then independently randomized into either Scenario 1, Scenario 2, or Scenario 3.

[5] This assumption is reasonable because a less effective vaccine might not be able to reach the market at all.

Figure 2. 1: Group 1: Introduce peers' action after initial decision

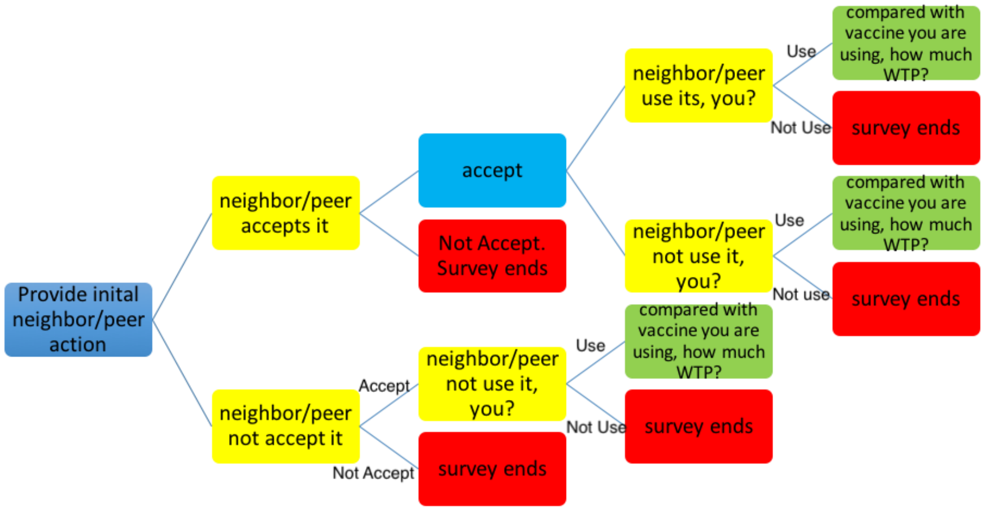

Figure 2. 2: Group 2: Introduce peers' action at the beginning.

2.4.2 Data Collected from the Pilot Project

Invitation to participate in the questionnaire was distributed by email to the dairy farmers in Alberta, Saskatchewan, Manitoba, Quebec, and Ontario. From February 2018 to July 2018 we received 240 attempts; 25 of them completed all the questions. Among the 215 uncompleted attempts, 10 quit after reading the consent, 2 resigned from the questionnaire after choosing the preference between "neighbor" and "peer", 7 left after reading the introduction, and 178 stopped immediately after the group assignment. Three observations were dropped because they were repeated attempts from the same individuals. For analysis purpose, only the observations from participants who answered at least one question about their perception of the vaccine were useable; thus, four more observations were dropped. That is, 11 of the uncompleted responses were usable. The summary of statistics is presented in Table 2. 2.

Table 2. 2: Basic summary of the responses

	Peer vs. Neighbor	Group 1 vs. Group 2	English vs. French
Completed	22:3	13:12	20:5
Useable	11:0	8:3	5:6
Uncompleted	17:0[6]	91:113	172:32
Total	51:3	112:128	197:43

At the beginning of the questionnaire, we provided the following definitions: "*A neighbour dairy farmer is one whose farm is within easy driving distance (e.g., within a 10-minute drive). A peer dairy farmer is one with whom you communicate with face-to-face, or through internet communication, farmer organizations, or another communication method."* Then, the dairy farmers were asked to choose between neighbors and peers as the preferred reference group. More than 90% of the respondents chose peers or indifference (Column 1, Table 2. 2). That is, rather than the geographical neighbor, most of the dairy farmers care more about the general Canadian dairy community.

All the participants were randomly assigned to Group 1 or Group 2. As expected, each of the participants who finished all the questions had an almost equal chance to be assigned to one of these two groups. However, after being assigned to Group 2, the respondents were more likely to leave the questionnaire halfway (Column 2, Table 2. 2). According to Table 2. 2, there were 197 out of 240 respondents using English, 20 out of 25 respondents who completed all the questions using English. Although almost half of the dairy farms were located in Quebec, 1/6 of all the participants were using French. It seems like English-speaking farmers were more willing to participate in this JD vaccine questionnaire.

[6] Only 17 of the respondents who left the questionnaire halfway reached to this question, and all of them chose "peers".

The dairy farmers' responses to the vaccine at the three decision stages, willingness to accept, willingness to use, and willingness to pay, were collected using the five-point scales (i.e., Likert scale). For example, a dairy farmer assigned to Group 2 would be asked "Suppose your peers accept that this vaccination is a valid control option for Johne's disease. Do you also accept that vaccination is a valid control option for Johne's disease, even if you would not use the vaccine?". The dairy farmer's response options were: Strongly do not accept, Do not accept, Neutral[7], Accept, Strongly accept.

2.5 Evidence from the Pilot Project

Twenty-five complete questionnaires were collected from the dairy farmers in the selected provinces, the present analysis is based on these complete responses. The background information of the dairy farmers and their farms is presented in Table 2.3. The average age range of the participants was between age 35 to age 44, and 88% (n=22) were male. Among the farmers who specified their dairy farming experience, 87.5% (n=21) had worked on a dairy farm at least 10 years. In terms of education, the average level was attended or completed college or university. Compared with the 2018 national level (92 cows), the average number of milking cows reported here was more (147 cows). According to the Canadian Dairy Information Centre, in 2017 the milk production per farm was 8,477 hectoliters, which is much lower than the data we collected. One reason is the production of milk is highly related to quota, and some farmers might feel sensitive about providing accurate information. Nine farmers chose "prefer not to say" suggested the farmers' concern as well.

[7] Throughout the questionnaire, "neutral" is considered to be a positive response.

Table 2. 3: Demographics of the participants

	Obs	Mean	SD	Min	Max
Age	25	35-44	1.21	18-24	55-64
Gender	25	1.24	0.72	1	4
Years of dairy	24	21.04	12.87	0	45
Education level	25	4.28	1.90	1	10
# of milking cows	24	147	102.82	38	450
Milk shipped/year	16	64,799	125,588	480	450,000
Farm size (hectares)	17	571	704	100	3,000

2.5.1 Group 1

In total, there were 19 participants in Group 1 provided full answers to their willingness to accept, use, and pay. Without knowing their peers' opinion, only one participant strongly did not accept the vaccine as a valid control option against JD (Column 1, Row 1, Table 2. 4). The other participants either agreed or strongly agreed the JD vaccine is a valid control option regardless of the JD prevalence scenario provided to them. In general, farmers were affected by their peers' action. After knowing that their peers had an opposite choice on the vaccine, two farmers flipped their initial decisions (one positive, one negative) and followed their peers. Knowing their peers did not accept the vaccine, 4/19 became less willing to accept the vaccine. However, 1/19 was even more willing to accept the vaccine given his/her peers rejected.

Table 2. 4: Group 1 - responses

	WTA	WTA2	WTU	WTU2
Negative	1	1	1	1
Neutral	1	1	0	3
Positive	17	17	17	14
total	19	19	18	18

Note. 1. For willingness to accept (WTA), "Negative" includes "strongly not accept" and "not accept"; "Positive" includes "strongly accept" and "accept". The same logic applies to willingness to use (WTU). 2. WTA2 means the willingness to accept the vaccine after the farmer knows peers' action. WTU2 means the willingness to use the vaccine after the farmer knows peers' action.

Among the 18 farmers who accepted the JD vaccine, 17 of them were initially willing to use the vaccine (Column 3, Row 3, Table 2. 4). The only farmer who did not want to use it changed his mind to neutral after knowing his peers were willing to use it. The willingness to use the vaccine became less positive when a negative peer's action was told; one farmer even changed to a negative response.

However, not all the farmers were willing to pay for the vaccine. Three farmers said they would pay zero dollars, and two farmers said they were willing to pay a price less than the price they paid for the vaccines they were currently using. The majority of the farmers were willing to pay as much as they paid for the vaccines they were currently using.

2.5.2 Group 2

In Group 2, twelve dairy farmers provided full responses. In this group, the participants were informed of his/her peers' action before they made any choice at each stage. Every participant was asked to make a choice on the vaccine based on both positive and negative neighbor actions. Starting from a positive peers' action, three farmers held a neutral attitude towards the vaccine's validity (Column 2, Table 2. 5). Later, when a negative peer's action was provided to the same participants, two of the three farmers positively accepted the vaccine. That is, when peers actions were provided in the first place, a negative peer's action was associated with a stronger willingness to accept then a positive peer's action.

Table 2. 5: Group 2 - responses

	Started with peers accepting the vaccine			Started with peers not accepting the vaccine	
	WTA	WTU_POS	WTU_NEG	WTA	WTU_NEG
Negative	0	0	0	0	0
Neutral	3	0	0	1	0
Positive	9	12	12	11	12
total	12	12	12	12	12

Note. 1. For willingness to accept (WTA), "Negative" includes "strongly not accept" and "not accept"; "Positive" includes "strongly accept" and "accept". The same logic applies to willingness to use (WTU). 2. WTU_POS means the willingness to accept the vaccine when positive peers' action is provided; 3. WTU_NEG means the willingness to use the vaccine when negative peers' action is provided.

2.5.3 Knowledge of Johne's Disease

All of the respondents had heard of JD before. This is not surprising because Johne's disease has been widely discussed in the dairy press and the potential relationship between Johne's disease and Crohn's disease has attracted much discussion recently. On average, the respondents rated the risk of JD in their provinces and their own farm from low to moderate. One farmer felt the JD risk was high in his province; five farmers marked the risk of JD in their farms as high or extremely high. 20 out of 25 reported that animals on their farm were tested for JD previously; 12 out of 20 admitted that at least one animal had tested positive for JD on their farms. Given the "iceberg effect"[8] associated with JD, the actual infected animals on their farms could be more than predicted from these results.

2.5.4 Information Sources

We explore the dairy farmers information sources with respect to animal health by distinguishing between the most accessed information source and the most trusted information source. The summary of farmers' responses is presented in Table 2. 6 and Table 2. 7. According to Table 2. 6,

[8] "Johne's disease conforms to the classical "iceberg effect" seen with infectious diseases, where a large proportion of animals may be infected with MAP but only a small proportion of animals develop pathology or clinical disease" (Dobson, Liggett, O'Brien, & Griffin, 2013).

the veterinarian is the most accessed information source regarding animal health. Peers are the second most accessed information source. Neighbours appeared in two dairy farmers' third most accessed information source list. Some dairy farmers relied on the federal government and provincial government as well. Pharmaceutical representatives were accessed for animal health almost as frequently as a textbook. Among all the eight information sources, family members were the least accessed source. Other information sources mentioned were dairy industry publications, Alberta Milk, online information, and milk producers.

Table 2. 6: Most accessed information sources regarding animal health

	Most accessed	Second accessed	Third accessed
Veterinarian	20	2	
Peers/	1	10	5
neighbors			2
Textbooks		1	3
Family member	1		
Pharmaceutical rep.		2	2
Government information (provincial)		2	4
Government information (federal)		1	1
Other	1	5	3
Total observations	23	23	20

Table 2. 7: Most trusted information sources regarding animal health

	Most trusted	Second trusted	Third trusted
Veterinarian	20	1	1
Peers/	1	5	8
neighbors		2	1
Textbooks		2	1
Family member		1	2
Pharmaceutical rep.		1	1
Government information (provincial)	2	3	1
Government information (federal)		4	4
Other		3	2
Total observations	23	22	21

The most trusted information sources were almost identical to the most accessed information sources (Table 2. 7). The three most frequently mentioned information sources were veterinarians, peers, and government (federal). The additional information sources given by the participants were output from the research community and agriculture magazines. That is, peers and neighbors, together are the second most accessed and trusted information sources for Canadian dairy farmers with respect to animal health questions.

2.6 Discussions

Given the limited sample size, conclusions that solely rely on the current pilot project should be considered suspicious. However, several interesting quantitative descriptions from the fieldwork reflected what the theoretical model suggested.

Peers matter. In the section of “information sources”, peers and neighbors are the second most frequently accessed and trusted information sources regarding animal health questions, only behind the veterinarians. Facing a wide array of veterinary products, peers, to some extent, reduce the information barrier between farmers and providers. By communicating with trusted peers, dairy farmers can learn more useful information about the services, and then make a choice after updating their beliefs. Not only did peers and neighbor behave as influential information sources, but also they affected dairy farmers’ choices. In Group 1, quite a few farmers overturned their original decision after knowing their peers chose the opposite. Peers’ positive feedback encourages farmers to behave more actively. As the model suggested, knowing the peers are paying efforts to control the disease generates peer pressure. Thus, farmers who initially did not want to take the vaccine would adjust their effort to keep up with their peers.

Despite the positive influence that peers play in terms of vaccine diffusion, it is likely that free-riders still exist. An eye-catching observation from the fieldwork is in Group 2, the willingness to accept the vaccine was stronger when farmers were told that peers did not accept the vaccine (3 neutral and 9 positive facing positive peers action; 1 neutral and 11 positive facing negative peers action; 2 farmers positively accepted the vaccine facing negative peer actions but turned to neutral facing positive peers action). This coincides with the theoretical implication – vaccination generates positive externalities that can be shared by other farmers. Knowing peers are likely to pay the effort to maintain herd health, some farmers were able to free-ride. A less straightforward interpretation is that in Group 1, even though most farmers tended to follow their peers, the only farmer who refused to accept the vaccine insisted on the negative choice after knowing his/her peers accepted. Of course, what we observed could be interpreted as some farmers do not trust their peers. But one of the two farmers who were less willing to accept the vaccine specified peers as his second accessed information source and third trusted information source with respect to bovine health. Trust may partially explain the behavior diversion from peers, but the whole story is definitely beyond that.

It is natural to ask why so many participants commenced but dropped the questionnaire. According to the connecting time reported by the system, the majority of participants exited the questionnaire after reading the concept page. This is where we described the objective of the questionnaire is to explore peers' effect on the dairy farmers' perception of a JD vaccine. It may be that some participants abandoned the questionnaire because it related to JD. JD takes a long time to develop and even using advanced diagnostic tools it can be difficult to detect the disease at the early stage. Therefore, despite the significant economic losses reported by the literature, dairy farmers' weak perception about JD is recorded as well. As pointed out by the model, dairy farmers allocate more efforts on the diseases that cause more visible losses. When the perceived risk of JD is not as high as other diseases, such as Mastitis and bovine viral diarrhea (BVD), the efforts paid by farmers are fewer. Moreover, although neighbors and peers are important to dairy farmers, the research concept of the peer effect might not be very interesting to dairy farmers.

One limitation of the data collection is the selection bias. It is possible that only farmers who consider JD as a more serious threat would be interested to participate, and the feedback from these farmers may overstate the positive willingness to take actions against JD. However, if this is true, it means policymakers should be more sophisticated when attempting to control for JD.

2.7 Conclusions

Under the supply management system, Canadian dairy farmers maximize profit as normal producers, but they do not compete with each other. They have one thing important to share: that is the animal health of the industry. To defend supply management, they have a stronger incentive to maintain the good reputation of their industry as if they are in a partnership. To do so, they work collaboratively to keep their animals healthy. However, like other partnerships, free-riding can occur when the benefits cannot be privatized while strong and effective monitoring is absent. Peer pressures and the potential losses associated with animal diseases force the farmers to pay more attention to diseases. Nevertheless, the actual effort paid by the farmers is below the optimal level, which makes it impossible to reduce the disease risk to zero. The pilot fieldwork confirmed that dairy farmers care about peers' opinions, and many dairy farmers' decisions were affected by their peers.

Peers play a positive role in improving farmers' efforts in controlling diseases. On one hand, peers serve as a valuable information source to assist farmers to update their belief of some veterinary services. In addition, the pressure from peers drives up the effort level.

The influence of external peer pressure depends on the likelihood of being caught or "cheating". Due to the asymmetric information and the large distance between farmers, perfect voluntary monitoring between dairy farmers is impractical. But if a policy aiming to monitor disease control and commit a certain penalty is available, optimal effort level is achievable. In our case, if vaccinating cows against JD is regulated by relevant policies, farmers' compliance would be higher. Lacking official policy support, free-riding is possible, and voluntary disease control cannot obtain the optimal result.

Internal pressure works when the dairy farmer feels guilty by taking fewer necessary efforts to control for JD. Dairy farmers in Canada share the benefits of a better reputation of the Canadian dairy industry. Also, the dairy organizations in Canada invest to encourage activities of the dairy farmers which promote farmers loyalty and team spirit. Both reasons increase the possibility that Canadian dairy farmers feel guilty when working less hard; thus, the peer effect is valid through internal peer pressure.

Substantial literature has documented that Johne's disease can cause significant economic losses. However, because JD is an infectious disease, some dairy farmers may choose to free-ride compared with their peers when controlling for JD. That is one reason why not all dairy farmers are willing to use and pay for the JD vaccine. Meanwhile, the disease progression pathway for JD is slow. Therefore, the cost caused by the disease is imposed on the farmers gradually. Compared with other diseases which caused rapid or immediate losses, JD receives inadequate attention from dairy farmers. A proper policy designed to promote dairy farmers' efforts to controlling JD is necessary.

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Chapter 3

Production and Cost Efficiency Changes under a Rights-Based Regime: Evidence from the Norwegian Purse Seine Fishery

3.1 Introduction

In Norway prior to the 1960s, no regulations existed relating to quantities of fish harvested. In an open-access fishery, overfishing, driven in large part due to competition for depletable fishing stocks, led to multiple crises in Norway's fishing industry. To cite two examples: in the 1960s, the Norwegian spring-spawning herring was depleted (Gullestad et al., 2013), and in the late 1980s, the Norwegian Arctic cod stock collapsed (Holm & Ranes, 1996). To restore fishing and maintain a sustainable industry, many policy changes and regulations were implemented. Most importantly, the Norwegian government implemented a rights-based management system where each vessel owner was given a quota of the fish stock.

A rights-based management system, in addition to managing stocks, in theory can benefit vessel owners by reducing costs, improving quality, and promoting productivity and efficiency (Casey, Dewees, Turris, & Wilen, 1995; Dupont & Grafton, 2000). Substantial empirical studies support the theoretical argument that fisheries benefit from quota systems in terms of, for example, efficiency, profitability, and resource rent (Dupont & Grafton, 2000; Grafton, Squires, & Fox, 2000; Kroetz, Sanchirico, Peña-Torres, & Novoa, 2017; Weninger, 1998). Nevertheless, only a few studies paint a comprehensive picture of how efficiency changes over time. In line with these studies, this paper assesses the efficiency changes using the stochastic frontier analysis and draws on data from the Norwegian purse seiners covering the period from 1994 to 2013.

The reforms reduced the fleet size significantly. The number of registered vessels with purse seine licenses declined 64% from 216 in 1980 to 78 in 2017 (Norwegian Directorate of Fisheries, 2018). Over against this, during the same period of time, capital investments in engine horsepower, vessel length, and vessel cargo capacity increased significantly (Nøstbakken, 2012; Standal & Asche, 2018). But this trend does not coincide with fluctuations in real fish price or catching quantity. This situation produces what the literature calls overcapacity. Nøstbakken (2006) extends this further and distinguishes between overcapacity and excess capacity. Both concepts address the mismatch between potential catch and actual catch, with overcapacity focusing long-term and excess capacity short-term (Nøstbakken, 2006). This mismatch of capital investment and catching quota/fish price over the long term calls into question just how efficient the reforms have been in the industry.

Inefficiencies in the Norwegian fisheries have been well-established in the literature. Guttormsen and Roll (2011) investigated the Norwegian groundfish fleet's technical efficiency in production. They found that more than 92% of the vessels' efficiency was less than 40%, and the possible reason was overcapacity. In particular, factory trawlers and fresh/freeze trawlers were more efficient than other groups, while the most efficient vessels were the smaller ones (Guttormsen & Roll, 2011). Asche and Roll (2018) estimated a short-run shadow revenue function and concluded that the technical efficiency in the Norwegian whitefish fishery was about 45%, and the allocative efficiency was about 54% (Asche & Roll, 2018). Greaker et al. (2017) calculated the optimal resource rent in the Norwegian fishery. Their empirical results showed that if all the catching quotas were harvested efficiently, the resource rent could be four times the observed resource rent in 2011 (Greaker et al., 2017).

Despite the evidence of inefficiencies in the Norwegian fishing industry, an exhaustive analysis of the fishery's long-term efficiency is lacking for the period of time when the quota system was introduced on a step-by-step basis. Our research contributes to this deficiency by focusing on one fleet of the overall industry, which basically has two major fisheries, pelagic and demersal. We leave aside the demersal. For the pelagic fishery, more than 50 percent of catching quotas are assigned to Norwegian purse seiners (Asche, Trond, Marianne, & Nils, 2015). This fleet has had the highest operating margin of profitability, at 29.8 % (Directorate of Fisheries, 2017).

Given the high profile of the purse seiners with respect to quotas and profitability, we deem a comprehensive investigation of the long-term efficiency and performance of this fleet of the Norwegian fishing industry necessary. Such a study is valuable for policymakers so that they can evaluate actual outcomes of their policies. And the Norwegian fishing industry benefits because it can evaluate how effective its implementation of and response to the policies have been. What is more, this study also carries value because purse seiners have received so little attention down to the present.

This paper analyzes the vessel-level panel data from the Directorate of Fisheries' Profitability Surveys, using Stochastic Frontier Analysis (SFA). Aigner et al. first introduced SFA in 1977. Since then, it has been adopted to measure efficiencies in various fields, such as transportation, foreign direct investment, trade, grain farming, the food industry, and fisheries (Grafton et al., 2000; Subal C Kumbhakar, Lien, & Hardaker, 2014; Lopez, He, & Azzam, 2018; Mastromarco, Serlenga, & Shin, 2012; Smith, 2012; Tingley, Pascoe, & Coglan, 2005). We address the following three efficiencies covering the period from 1994 to 2013: (1) production and cost; (2) technical and allocative; and (3) time-invariant and time-varying.

The relevant fishery reforms in the Norwegian purse seine fishery are illustrated immediately below. The detail of data is presented in Section 3; Section 4 describes the methodology; Section 5 reports the description of statistics and Section 6 presents the empirical results from SFA; further analysis of the efficiency change in the purse seine fleet is reported in Section 7; Conclusions follow in Section 8.

3.2 The Fishery Reforms in Norway

As a typical example of a common resource, the Norwegian fishery was altered for the resource exhaustion due to overfishing in the 1960s. To keep the Norwegian fishery sustainable, a series of complex management reforms have been implemented. The individual vessel quota (IVQ) management system is a significant start of the reforms. IVQ first assigns the Norwegian total allowable catch (TAC) amongst different segments of fishing fleets. Then, each fleet subdivides the total catch in terms of quota to different vessels groups. Finally, the group quota is distributed among the participating vessels in each group.

The Norwegian purse seine fleet was one of the fleets where the management reform started (Hannesson, 2007). Starting from 1978, purse seine owners cannot catch beyond the quota they received. Although there were no official rules, additional quota can be obtained by purchasing and scrapping a vessel with quota since the inception of IVQ. Later, the unit quota system (UQS) came into effect and it specified: vessel owners could purchase additional quota from retirement vessels and use the quota for 13 or 18 years (Ekerhovd, 2007; Nøstbakken, 2012). UQS began to manage the pure purse seiners in 1996, it extended to purse seiners with industrial trawler licenses in 2002. In March 2005 the unit quota system was replaced by the structural quota system (SQS), which allows quota purchasers to own the quota permanently (Norwegian Directorate of Fisheries, 2018). However, from October 2005 to June 2007, the Norwegian government were reviewing the management regime and did not assign any new quota during this period (Norwegian Directorate of Fisheries, 2018).

Following the introduction of these quota transfer policies, the fish stock has been recovering, and the number of vessels has decreased steadily in Norway (Diekert & Schweder, 2017). On the other hand, the rights-based fishing systems motivated vessel owners to maximize their share of catch (Asche, Eggert, Gudmundsson, Hoff, & Pascoe, 2008; Asche, Gordon, & Jensen, 2007; OECD, 2011). As a result, larger vessels were built in order to win more catching shares. Multiple studies have found that overcapacity is unprofitable and limits the resource rent generation (Asche, Bjørndal, & Gordon, 2009; Standal, 2005). In other words, the quota has not been harvested at the minimum cost (Greaker, Grimsrud, & Lindholt, 2017).

3.3 Data

Most of the data used in this paper came from the annual surveys of the Norwegian Directorate of Fisheries (DoF). This is an unbalanced panel dataset representing Norwegian purse seiners over the period of 1994 to 2013. This dataset includes information on catching quantity by species, vessel and gear maintenance cost, vessel and other insurance expenditure, fuel expenditure, vessel characteristics such as length, tonnage, and age.

Given the lack of information on some inputs in DoF, several variables were retrieved from Statistics Norway and OECD-Data. First, as the total labor cost was a predetermined fraction of the total catch value, the average manufacturer salary from Statistics Norway was used to measure the wage of labor as the opportunity cost. Second, DoF collected the expenditure on fuel, but not the quantity of fuel consumed. Therefore, the quantity of fuel was calculated by dividing the total expenditure by the fuel price. Third, capital price in the long-run was measured by the real interest rate, and the real interest rate was calculated with the Norwegian interest rate and CPI information reported by OECD-Data. In addition, values and costs were measured in Kroner, and they were converted into 2015-Kroner value using Norwegian CPI reported by OECD-DATA.

3.4 Methodology

Producers maximize profit by choosing an optimal level of inputs to produce an optimal level of outputs. Any deviation from the optimal behavior is usually considered as noise due to random shocks. Stochastic frontier analysis (SFA) separates out inefficiencies from the error term. Rather than the parameters of a production or cost function, SFA focuses on disentangling inefficiencies from the error term.

Traditional SFA technologies, such as Battese and Coelli (1992) and Battese and Coelli (1995), assumed that all the fixed effect or random effect is time-invariant inefficiency (Subal C Kumbhakar et al., 2014). However, as pointed by Greene, some firm-specific effects are not part of the inefficiencies, and he recommended the "true" fixed or random effect models to separate firm-specific effects and inefficiencies (Willam Greene, 2005; William Greene, 2005; Subal C Kumbhakar et al., 2014). After separating the constant heterogeneity from inefficiencies, the remaining challenge is to distinguish the time-invariant inefficiency from the time-varying inefficiency. Some deviations from the optimal path occur in the short run for a variety of reasons, such as a policy change, and usual temperature, and the associated inefficiency can be eliminated in the long-run. This type of inefficiency is categorized as the time-varying inefficiency. It is different from the time-invariant inefficiency which is persistent over time. This paper adopts an updated SFA technology introduced by Kumbhakar et al. (Subal C Kumbhakar et al., 2014) and

Colombi et al. (Colombi, Kumbhakar, Martini, & Vittadini, 2014) to separate the heterogeneity, the time-varying inefficiency, and the time-invariant inefficiency.

Although the Norwegian purse seiners are regulated by quotas, vessel owners can make arbitrary decisions on harvest under the maximum limit. Given that, a production function is estimated first, and a cost frontier is derived from the production frontier based on the duality of production functions and cost functions. A Cobb-Douglas functional form is employed because the parameters could be easily interpreted with economic meanings. Considering the heterogeneity in vessels owners' management skills and each vessels' unique characteristics, a fixed-effect model is estimated. In addition to technical inefficiency, this paper also estimates allocative inefficiency.

3.4.1 Production Function

A generalized production function can be written as:

$$y_{it} = y_{it}^{*} + \varepsilon_{it},$$

Where ${y_{it}}^{*} = f(x_{it})$ is vessel i 's optimal output level at time t free of inefficiency; ε_{it} is the composed error term. In particular, there are four components in ε_{it}:

$$\varepsilon_{it} = \mu_i + v_{it} - \eta_i - u_{it}$$

$$\mu_i \sim N(0, \sigma_{\mu}^2)$$

$$v_{it} \sim N(0, \sigma_v^2)$$

$$\eta_i \sim N^{+}(0, \sigma_{\eta}^2)$$

$$u_{it} \sim N^{+}(0, \sigma_u^2)$$

The firm effect is measured by μ_i, it captures the heterogeneity of individual vessel which is not part of the inefficiency; v_{it} is the unobservable noise term which is not part of the inefficiency neither; $\eta_i > 0$ is the time-invariant or persistent inefficiency; $u_{it} > 0$ represents the time-varying inefficiency. η_i and u_{it} are assumed to be positive in a production function, that is, inefficiencies result in less production using the same level of inputs.

The associated Cobb-Douglas production function is:

$$\mathrm{In}y_{it}^{*} = \beta_0 + \beta_1 * \ln L_{it} + \beta_2 * \ln \mathrm{F}_{it} + \beta_3 * \ln \mathrm{K} + \beta_4 * \ln \mathrm{S}_\mathrm{t} + +\beta_5 * t$$

$$\mathrm{In}y_{it} = \beta_0 + \beta_1 * \ln L_{it} + \beta_2 * \ln \mathrm{F}_{it} + \beta_3 * \ln \mathrm{K} + \beta_4 * \ln \mathrm{S}_\mathrm{t} + \beta_5 * t + \varepsilon_{\mathrm{it}}$$

$y_{it}{}^{*}$ is vessel i's optimal output without inefficiencies in year t. y_{it} is vessel i's actual catching quantity in year t, it is the sum of catching quantities of Norwegian Spring herring, North Sea herring, mackerel, capelin, blue whiting, sand eel, and other fishes. Except for sand eel and other fishes, the harvest of fishes is regulated by quotas. L_{it} denotes the number of full-time equivalent workers working on vessel i in year t. F_{it} is vessel i's fuel consumption in year t. S_t is the weighted average stocks of the regulated species. β_5 captures the time trending in the production function.

In the short run, capital is considered to be fixed, and it is measured with the length of vessels. In the long run, capital is assumed to be adjustable, and the total expenditure on capital is measured by the sum of the maintenance expenditure on the vessel and the gear(s). Suppose the opportunity cost of the capital expenditure is to deposit the money into the bank, then the price of capital is the interest rate. Therefore, the quantity of capital is defined as the sum of maintenance expenditure on vessel and gear(s) divided by interest rate.

The composed error term is split into four components: $\varepsilon_{it} = \mu_i + v_{it} - \eta_i - u_{it}$. The time-varying technical efficiency in production is:

$$\text{Time} - \text{varying efficiency} = \frac{y_{it} * e^{-u_{it}}}{y_{it}{}^{*}} = e^{-u_{it}}$$

The time-invariant technical efficiency in production is:

$$\text{Time} - \text{invariant efficiency} = \frac{y_{it} * e^{-\eta_i}}{y_{it}{}^{*}} = e^{-\eta_i}$$

The overall technical efficiency in production is:

$$\text{Overall technical efficiency} = \frac{y_{it} * e^{-\eta_i - u_{it}}}{y_{it}{}^{*}} = e^{-(\eta_i + u_{it})} = TER * TEP$$

The overall technical inefficiency in production is:

$$\text{Overall technical inefficiency} = 1 - \text{OTE} = 1 - e^{-(\eta_i + u_{it})}$$

3.4.2 Allocative Efficiency and Conditional Input Demand Function

After estimating the production function, with the input price information, we can derive the indirect cost function and the conditional input demand functions. For simplification, we drop the subscriptions for vessels and time. Suppose $lny = \ln f(x) + v - u$, where v is the random noise, and u is the overall production technical inefficiency. The first order condition of the cost minimization can be rearranged as:

$$\frac{f_j}{f_i} = \frac{w_j}{w_i} e^{\xi_{ij}}$$

If input i and input j are allocated at the optimal level, $\frac{f_j}{f_i} = \frac{w_j}{w_i}, \xi_{ij} = 0$ and $e^{\xi_{ij}} = 1$; if input j is overused relative to input i, $\frac{f_j}{f_i} < \frac{w_j}{w_i}, \xi_{ij} < 0, e^{\xi_{ij}} < 1$; if input j is underused relative to input i,

$\frac{f_j}{f_i} > \frac{w_j}{w_i}, \xi_{ij} > 0, e^{\xi_{ij}} > 1$. Because ξ_{ij} indicates whether two inputs are allocated efficiently, we use it as the allocative inefficiency index. In the short run, fuel is chosen to be the numeraire, and in the long run, capital is the numeraire.

Using the production function and the first order condition of the cost-minimizing problem, we are able to solve for the conditional input demand functions.

$$\mathrm{lnX_j} = \mathrm{a_j} + \frac{1}{r}\sum_{i=1}^{J} \mathrm{\alpha_i lnP_j} - \mathrm{lnP_j} + \frac{1}{r}\mathrm{lny} + \frac{1}{r}\sum_{i=2}^{J} \mathrm{\alpha_i}\xi_{\mathrm{i}} - \xi_{\mathrm{j}} - \frac{1}{r}(\mathrm{v} - \mathrm{u}), j = 2, \dots J$$

$$\mathrm{lnX_1} = \mathrm{a_1} + \frac{1}{r}\sum_{i=1}^{J} \mathrm{\alpha_i lnP_j} - \mathrm{lnP_1} + \frac{1}{r}\mathrm{lny} + \frac{1}{r}\sum_{i=2}^{J} \mathrm{\alpha_i}\xi_{\mathrm{i}} - \frac{1}{r}(\mathrm{v} - \mathrm{u}), j = 1$$

$$\mathrm{a_j} = \mathrm{ln\alpha_j} - \frac{1}{r}\left[\alpha_0 + \sum_{i=1}^{J} \alpha_i ln\alpha_i\right]$$

X_1 represents the numeraire, which is fuel in the short run and capital in the long run.

3.5 Descriptive Statistics

The unbalanced panel dataset utilized here is a representative sample for the Norwegian purse seiners consisting of 1,619 observations from 254 vessels in the period of 1994 — 2013. Table 3. 1 shows that the average length and cargo capacity of the purse seiners exhibited a robust upward trend (Column 2 and 3, Table 3. 1). However, the increasing investment in vessel size and capacity does not match the production level or the fish price change. The average production climbed quickly in the period of 1994-1998, it remained at a high level till 2010 and then declined considerably (Column 4, Table 3. 1). The real prices of fishes were relatively stable over the study period (Figure 3. 2).

Table 3. 1: Summary of the sample fleet (1994-2013)

Year	Number of Vessels	Average cargo-carrying capacity (tonnage)	Average vessel length (m)	Average catch per vessel (tonnes)	Average age of vessels
1994	50	573.74	46.26	7996135	29.88
1995	53	601.64	46.94	8147087	31.36
1996	62	630.21	47.08	8660654	31.39
1997	53	618.89	46.84	9543440	33.38
1998	103	872.68	51.05	1.30E+07	26.29
1999	89	887.03	51.05	1.17E+07	25.25
2000	108	984.32	53.09	1.26E+07	21.50
2001	104	1029.53	53.15	1.33E+07	20.41
2002	109	1051.13	53.95	1.36E+07	19.61
2003	99	1122.87	56	1.33E+07	18.67
2004	93	1150.87	55.26	1.33E+07	17.19
2005	93	1312.88	58.47	1.30E+07	15.18
2006	86	1285.07	57.81	1.17E+07	15.53
2007	82	1319.71	58.44	1.23E+07	15.49
2008	86	1388.17	60.03	1.32E+07	15.90
2009	74	1548.82	62.5	1.37E+07	15.70
2010	77	1455.14	61.55	1.35E+07	17.45
2011	74	1518.61	61.97	1.06E+07	18.14
2012	64	1604.66	63.13	1.01E+07	17.50
2013	66	1556.91	62.52	9038576	17.80

Another interesting observation from Table 3. 1 is that the purse seine fleet experienced a craze of vessel replacement from 1997 to 2005 – vessel owners started to bring in newer vessels which drove the average age of vessels down. Given that the average vessel age was over 30 years prior to 1997, the reason for the vessel replacement might be the relatively aged vessels were unable to serve the production requirement. Actually, the Norwegian authorities financially supported vessel and technology evolutions in reducing operational cost (Flåten & Isaksen, 1998; OECD, 2000). For example, based on an agreement between the Norwegian Fishermen’s Association and the government, the Norwegian National Fishery Bank set transfers for vessel building and rebuilding, the amount was NOK 30.5 million in 1995, NOK 92 million in 1996 and 1997 (OECD, 1998, 2000). The abovementioned changes in the purse seine fleets are also visually presented in Figure 3. 1.

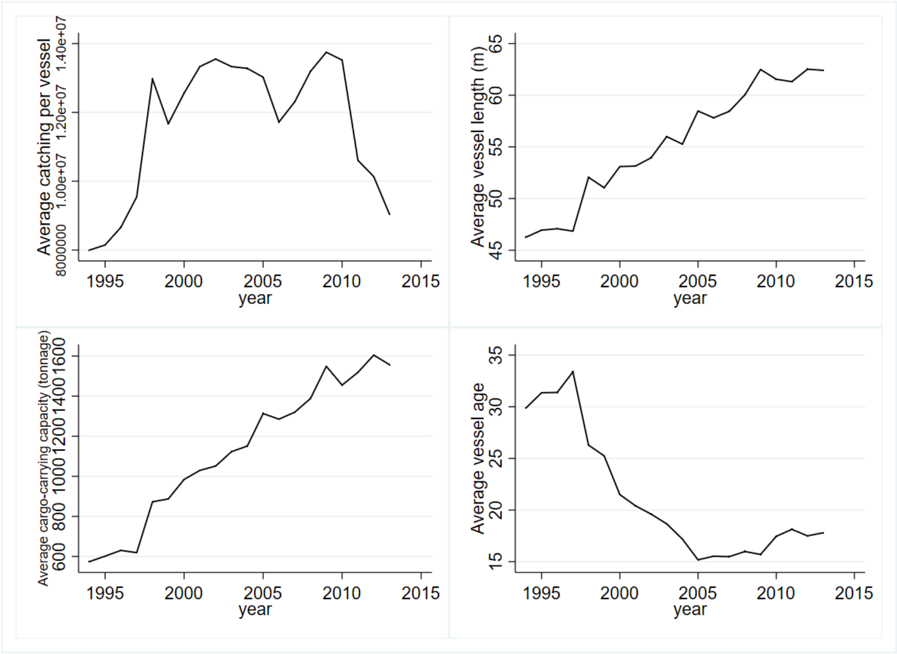

Figure 3. 1: Summary statistics

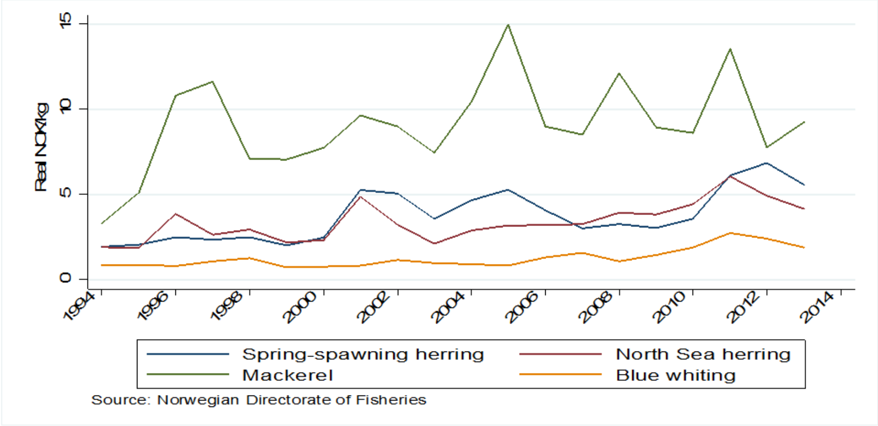

Figure 3. 2: Real fish prices by species

Larger vessels were brought into the purse seine fleet. Figure 3. 3 (Panel A) illustrates that the share of vessels below 60m has dropped greatly while the share of vessels between 60m and 80m has increased since 1996. The vessel share changes are also echoed in the catching share changes. Figure 3. 3 (Panel B) shows that the 60-80m vessel group has taken higher catching share, but the catching share of the smaller vessels have declined over the past decade. When allocating quota among vessels, the scheme is in favor of smaller vessels, “that is, the largest vessels get a proportionally smaller quota than the small vessels.” (National Research Council, 1999). If so, why do larger vessels (60-80m) become the mainstream? One interception could be the larger vessels have the advantage of economic scale (Quotas, Commission on Geosciences, Studies, & Council, 1999), thus more vessel owners prefer larger vessels.

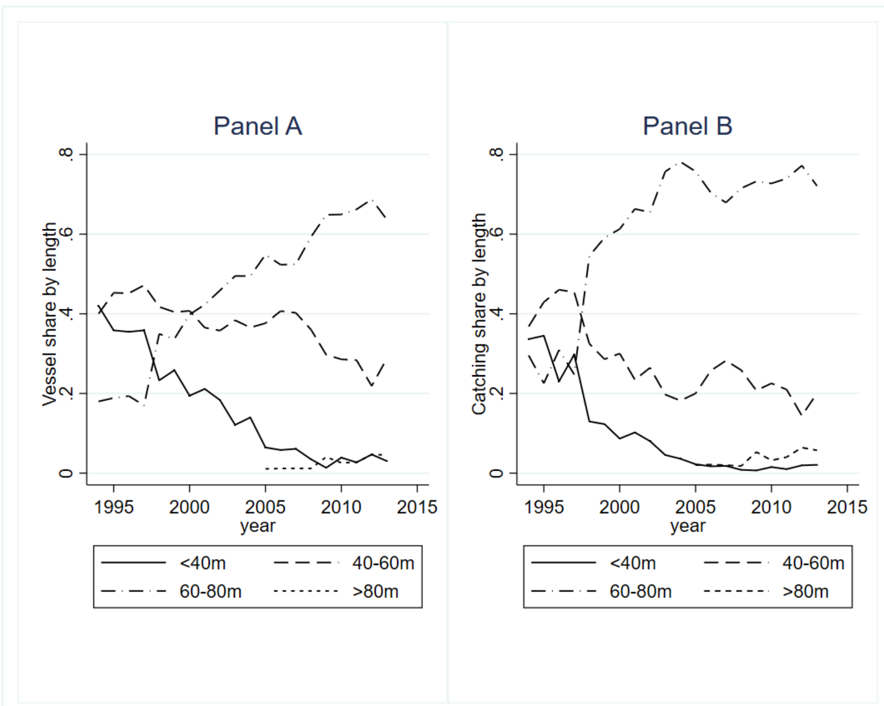

Figure 3. 3: Vessel share and catch share by vessel length

As shown in Figure 3. 3, the most significant shift in both vessel-share and catching-share happened in around 1997. Moreover, we observed striking changes in cargo capacity, length of vessels, and age of vessels at the same time. Maybe catching quantity boost around 1997 encouraged vessel owners to bring in larger and newer vessels. Another factor might play a role is the quota policy change. In 1996, the policy that regulating the quota transfer between vessels came into effect among pure purse seiners. The policy change makes catching quota a valuable asset, therefore vessel owners are able to apply for a loan on pledge of the quota from the banks. Indeed, the financial institutions consider quotas as better security for loans compared to the vessels (Nøstbakken, 2012). Namely, vessel owners have better financial abilities to replace or rebuild vessels because of the quota transfer policy.

Table 3. 2: Summary of inputs (1994-2013)

Year	Labor per vessel	Average length of vessels (m)	Fuel usage per vessel	Average maintenance expenditure (NOK)
1994	7.92	46.26	19042.25	2.95e+07
1995	8.30	46.94	17390.79	3.54e+07
1996	8.06	47.08	19949.70	4.84e+07
1997	7.84	46.84	19088.39	5.47e+07
1998	8.70	51.05	22819.83	7.83e+07
1999	8.30	51.05	24157.40	6.03e+07
2000	8.57	53.09	32028.67	5.54e+07
2001	8.48	53.15	34540.41	6.97e+07
2002	8.59	53.95	32759.61	7.27e+07
2003	8.48	56	33103.73	7.27e+07
2004	8.29	55.26	40061.04	8e+07
2005	8.53	58.47	40781.02	1.01e+08
2006	8.23	57.81	32988.51	8.94e+07
2007	8.23	58.44	38213.43	8.55e+07
2008	8.57	60.03	37864.06	1.01e+08
2009	9.03	62.5	35800.36	1.28e+08
2010	9.05	61.55	35807.98	1.58e+08
2011	9.33	61.97	28911.78	1.89e+08
2012	9.30	63.13	29274.62	2.49e+08
2013	9.04	62.52	27830.69	1.79e+08

Table 3. 2 reports the summary of major inputs consumed by the purse seiners. From 1994 to 2013, the usage of labor slightly increased. The vessel length increased by 37% from 46m in 1994 to more than 52m in 2013. Considering the robust increase in vessel size, it is not supervising to fins that the maintenance has climbed 500% in 20 years. The usage of fuel peaked in 2005, after that fuel usage declined.

3.6 Stochastic Frontier Analysis Results

The underlying hypothesis is that vessel owners produce at the minimum cost to maximize profit. The estimated parameters of the production function are reported in Table 3. 3. In the short run, labor, fuel, and capital have significantly positive effects on production at 5% or 1% level, but the biomass does not affect production significantly. In the long run, the same as biomass, labor has no significant impact on production. In the short run, the capital elasticity of production is statistically significantly positive, which indicates that larger vessels caught more fish. It is not only because the more capacity of the larger vessels, but also reflects the fact that larger vessels are allocated with more fishing quota. Compared with the short run, the capital elasticity of production reduces from 0.8 to 0.13 in the long run. The fuel elasticity of production is approximately 0.5 at 1% level in both short run and long run.

As a pre-test for the existence of production inefficiency, we tested on the skewness of the residual (Row 9, Table 3. 3). The rationale is the composed error term is a mix of a normal distributed noise and inefficiencies which negatively affect production. Therefore, the error term should skew to the left if inefficiency presents in the production (Subal C. Kumbhakar, Wang, & Horncastle, 2015). The skewness tests support the statement that the error term is left-skewed distributed at 1% level in both short run and long run.

Table 3. 3: Parameter estimation of the production stochastic frontier

variable	short run	long run
constant	71.47***	77.95***
Capital	0.80***	0.13***
labor	0.12**	0.05
fuel	0.47***	0.46***
year	-0.03***	-0.03***
Biomass	0.15	-0.02
No. of Obs	1,625	1,625
Fixed-effects	Yes	Yes
Skewness test	***	***
Return to scale	0.58	0.64

Note. 1. A skewness test was performed to test the null hypothesis of no skewness in the residuals. This is rejected confidently at the 1% level of significance.
* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.

3.6.1 Technical Efficiency in Production

The estimation of production efficiency is presented in segment 1 Table 3. 4. In the short run, capital is measured with the fixed vessel length. The overall technical efficiency in production is 64%, which means on average, using the available inputs, the vessel owners caught 64% of the maximum quantity of fish due to technical inefficiency. In other words, to catch the same amount of fish, the purse seiners could have reduced the inputs significantly by eliminating technical inefficiency. When capital is adjustable in the long run, the overall technical efficiency in production is 56%, 8% lower than the short run. In both short run and long run, the time-varying efficiency is 88%, higher than the time-invariant efficiency.

Table 3. 4: Efficiency scores

Efficiency	short -run average	long-run average
Production		
Overall technical efficiency	0.64	0.56
Time-varying technical efficiency	0.88	0.88
Persistent technical efficiency	0.72	0.64
Cost - Technical efficiency		
Total cost increased by technical inefficiency	0.93	1.04
Capital increases by technical inefficiency	NA	1.04
Total cost increases due to technical inefficiency in capital	NA	0.33
Labor increase by technical inefficiency	0.93	1.04
Total cost increases due to technical inefficiency in labor	0.19	0.07
Fuel increases by technical inefficiency	0.93	1.04
Total cost increases due to technical inefficiency in fuel	0.75	0.65
Cost - Allocative efficiency		
Total cost increased by allocative inefficiency	0.32	2.72
Capital increase by allocative inefficiency	NA	8.86
Total cost increases due to allocative inefficiency in capital	NA	2.78
Labor increase by allocative inefficiency	2.59	4.28
Total cost increases due to allocative inefficiency in labor	0.52	0.28
Fuel increase by allocative inefficiency	-0.25	-0.53
Total cost increases due to allocative inefficiency in fuel	-0.20	-0.33

Figure 3. 4 depicts the time-varying and time-invariant efficiency changes over time. The time-varying efficiencies maintain above 80% with some variations. Events that less likely to be repeated contribute to the variations in the time-varying efficiency. Therefore, the fluctuation in time-varying efficiency might be a result of policy changes, or fishing production adjustments. More discussions on the technical efficiency changes are presented in Section 7. The quota transaction policies were changed among different purse seine groups in 1996, 2002, and 2006. We will investigate the efficiency impact of these policy changes in next section as well, but a general impression from Figure 3. 4 is that the policy changes did not have a clear impact, either positive or negative, on technical efficiencies.

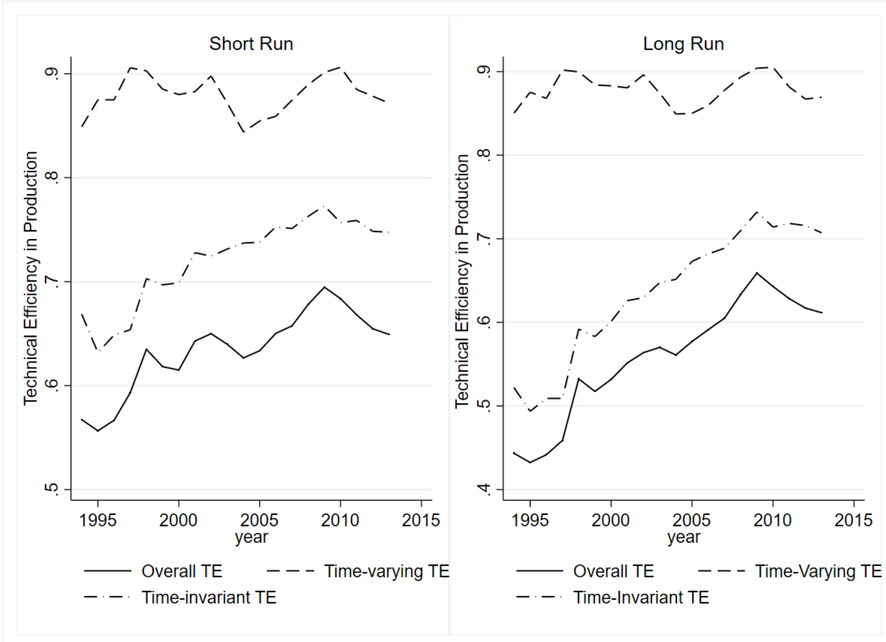

Figure 3. 4: Technical efficiency in production

The time-invariant efficiency is lower than the time-varying efficiency, but it increases by 10% from 1994 to 2013 (Figure 3. 4). Factors can potentially affect time-invariant efficiencies include the characteristics of the Norwegian fisheries, the union of the fishermen, skills of the fishermen, etc. Many changes took place in the Norway fishery industry. The Norway fishery resources changed from open access to right-based regulation; the vessel population reduced, and the total number of fishermen also declined; newer and larger vessels were introduced into the fleets. When the fishing right is privatized with quota, the captains' behavior might be different. Previously, they caught as much as they could, but now they have stronger incentives to produce more efficiently because they are not allowed to catch beyond the quota limit. Moreover, some vessel owners and fishermen withdrew from the fishery industry corresponding to the reforms. It is plausible to expect that vessel owners with poor management skills are more willing to sell their vessels for cash and exit the industry; similarly, only those experienced and skillful fishermen are more likely to stay in the industry. As a result, the overall skills in the industry is enhanced, the time-invariant efficiency also improves. Besides, as newer and larger vessels are replacing the aged vessels, the updated equipment, and better technologies are also introduced. The evolutions in vessels and technologies account for some time-invariant efficiency improvement as well.

3.6.2 Technical and Allocative Efficiencies in Cost

The second segment in Table 3. 4 reports the input demand and cost increase due to technical inefficiency. In the short run, technical inefficiency raises the usage of labor and fuel by 93%, and it increases the total cost on labor and fuel by 93%. The fuel expenditure contributes to a larger share of the increased cost. Technical inefficiency, in the long run, increased the usage of labor, fuel, capital, as well as the total cost by 104%, which is higher than the short run. Fuel expenditure accounts for 63% of the total cost waste, capital accounts for 32%, and the impact of labor is neglectable.

Allocative efficiency is a relative concept, and it involves the comparison of different input usage. The allocative inefficiency index is reported in Table 3. 5. In the short run, labor was overused relative to fuel by on all vessels in the sample. In the long run, capital is overused relative to both labor and fuel: all the vessels overuse capital compared to fuel, and 86% of the vessels overuse capital compared to labor. The same as the short run, all the vessels overuse labor relative to fuel in the long run.

Segment 3, Table 3. 4 illustrates how allocative inefficiency affects input demand and cost. In the short run, labor usage is 259% more than its optimal level, and fuel usage is 25% less than its optimal level. The total cost is increased by 32% due to the misallocation between labor and fuel. In the long run, labor is overused by 428% of its optimal level, but it only causes a 28% increase in the total cost. Fuel usage is 53% below its optimal level due to allocative inefficiency, and the underuse in fuel reduces the total cost by 33%. The actual capital usage is almost 10 times as its optimal level, and capital overuse causes a 278% increase in total cost.

Table 3. 5: Allocative inefficiency index

	Mean	SD	Min	Max
Short-run				
ξ_{fl}	-1.45	0.59	-3.36	-0.03
Long-run				
ξ_{fl}	-2.32	0.59	-4.23	-0.90
ξ_{kl}	0.59	0.54	-1.89	2.19
ξ_{kf}	2.91	0.71	0.57	5.37

Note. Input i represents the numeraire. $\frac{f_j}{f_\mathrm{i}} = \frac{w_j}{w_\mathrm{i}} e^{\xi_{\mathrm{i}j}}$, $\xi_{\mathrm{i}j} = 0$ means inputs i and j are allocated efficiently; $\xi_{\mathrm{i}j} < 0$ means input j is overused relative to input i; and $\xi_{\mathrm{i}j} > 0$ means input j is underused relative to input i.

According to Table 3. 4, the technical inefficiency together with the allocative inefficiency increases the total cost by 125% in the short run, and 376% in the long run. The technical inefficiency leads to more cost waste than the allocative inefficiency when only labor and fuel are analyzed in the short run. However, allocative inefficiency is a more critical problem in the long run when capital is included in the analysis. Why does allocative inefficiency cause more waste than technical inefficiency in the long run? When capital is fixed in the short run, there is not too much that the captain or the fishermen can do to reduce the technology inefficiencies. Alternatively, they might focus on allocating labor and fuel more efficiently. Thus, in the short run, allocative efficiency is higher than technical efficiency. When it comes to the long run, some vessels withdrew from the fleet, but their quota would be redistributed among the remaining vessels. As a result, each vessel might expect to receive more quota. Induced by this expectation, the vessel owners invest in vessels and technologies. The technology evolution might promote technical efficiencies. But a large amount of capital investment may distort the resource allocation, thus allocative inefficiency causes large cost waste. Nevertheless, it does not mean that investment in vessels and technologies is useless. It does take time for the individual vessel, the purse seine fleet, and the industry to absorb the cost and realize the benefit gradually.

Figure 3. 5 shows that the cost waste due to technical and allocative inefficiencies decline over time. That is, both efficiencies improved during the study period. In addition to the evolutions in vessels and technologies discussed above, the improvement in captains' management skills and workers' productivities can also plausibly explain the positive trend in efficiencies.

Figure 3. 5: Efficiency change over time

3.6.3 Vessel Length and Efficiency

Given the upward trend in vessel length over time, and the misallocation between capital and other inputs, a further investigation of the relation between capital and efficiencies is implemented. Figure 3. 6 plots the efficiencies changes by vessel length in both the short run and long run. The same as what we found previously, the technical inefficiency causes more cost waste in the short run, and the allocative inefficiency causes more cost waste in the long run. In both the short run and long run, vessels between 40m-80m are more technically efficient. It might be because 40m-80m is the ideal vessel size given the production requirement. The allocative efficiency is lower when the vessels are below 40m, but it is not obviously higher when vessels are above 80m.

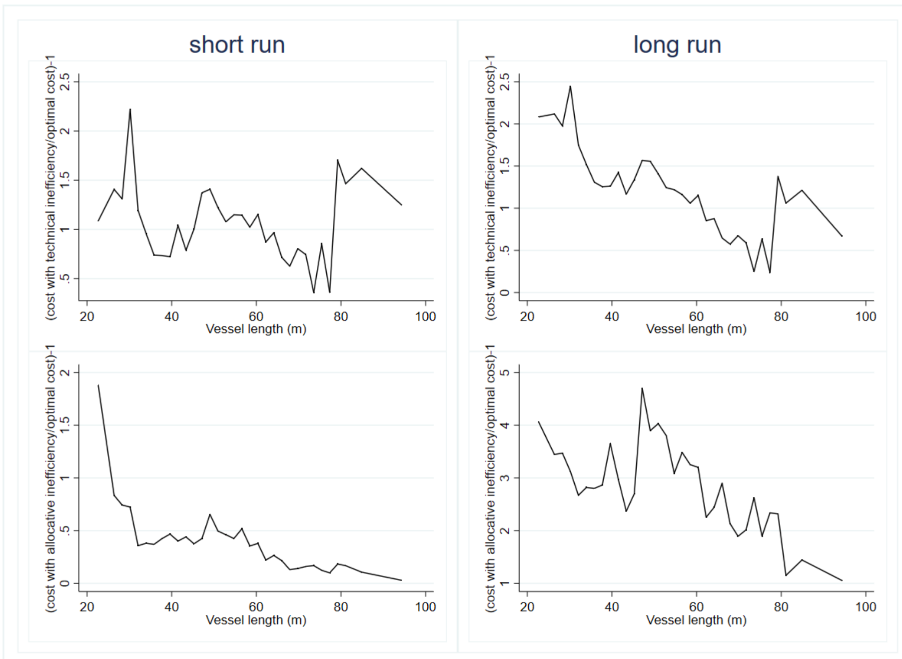

Figure 3. 6: Efficiency change by vessel length

Another impressive observation from Figure 3. 6 is when the vessel size is controlled, the allocative inefficiency leads to more cost waste in the long run than the short run. Recall that the long-run cost includes capital expenditure, the maintenance cost for vessels and gears, in addition to the short-run cost. That is, the investment in vessel length and capacity not only increases the capital input when the vessels are upgraded, it also requires a higher level of maintenance expenditure in the long term.

Further, all the vessels are divided into four categories by length as shown in Table 3. 6. We performed pairwise comparisons of the average efficiencies to provide further insights into the relationship between efficiencies and the vessel length. From the most efficient to the least efficient, the efficiency ranking is reported in Table 3. 7. The vessels in the 60-80m group are the most technically efficient; the vessels above 80m is the most allocatively efficient.

Above all, there is no clear trend in technical efficiencies as the vessel becomes longer. When vessel length is below 40m, efficiencies improve more significantly as vessel size increases. The overall efficiencies are the highest when vessels are between 40m-80m, but the positive association between vessel length and efficiencies are less obvious. The technical efficiency decreases dramatically when the vessel length goes beyond 80m. That is, in terms of efficiencies, it is not the larger the better or the smaller the better. To produce efficiently, the vessel size is an important factor, but it is by no mean the only part. The vessel owners need to take the actual production requirement into consideration when deciding on capital investments.

Table 3. 6: Efficiency differences by length of vessels

	<40m	40-60m	60-80m	<40m	40-60m	60-80m
		Short-run			Long-run	
Total cost increased by technical inefficiency						
40-60m	0.14***			-0.22***		
60-80m	-0.15***	-0.29***		-0.80***	-0.58***	
>80m	0.50***	0.35**	0.64***	-0.54***	-0.32**	0.26**
Total cost increased by allocative inefficiency						
40-60m	-0.25			0.18		
60-80m	-0.28***	-0.26***		-0.81***	-0.99***	
>80m	-0.37***	-0.35***	-0.09	-1.82***	-2.00***	-1.02*

Note. The symbol + (-) indicates the efficiency level of the horizontal category is lower (higher) than the efficiency level of the vertical category.
* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.

Table 3. 7: Efficiency ranking by length of vessels

Ranking	Short-run	Long-run
Cost increased by technical inefficiency		
1	60m-80m	60m-80m
2	<40m	>80m
3	40m-60m	40-60m
4	>80m	<40m
Cost increased by allocative inefficiency		
1	>80m	>80m
2	60m-80m	60m-80m
3	40m-60m	<40m
4	<40m	40m-60m

Note. From 1 to 4, the efficiency level decreases.

3.7 Efficiency Change in Different Vessel Groups

According to the fishing license a vessel holds, the vessels in our study sample are categorized into three groups: pure purse seiners (PPS), purse seiners with industrial trawlers (IT), and purse seiners with blue whiting trawlers (BW). IT and BW are purse seiners equipped with specific trawlers enabling them to catch additional species that cannot be fished by regular purse seining. The accumulated catching shares on the basis of species for each group are listed in Table 3. 8. In general, Norwegian spring herring is an important species for all the three groups. A large proportion of the IT's catching is from sand eel, while the other two groups almost catch no sand eel.

In addition to the difference in fishing method, the transferrable quota policies were introduced into the three groups at different time. In 1996, PPS started to be allowed to transfer quotas under the Unit quota system (UQS), the purse seiners with industrial trawler licensed is regulated by the system from 2002, and the quota transfers in the BW group are subject to certain regulations in 2006 under the Structural quota system (SQS). Considering the heterogeneity associated with the three groups, it is worth looking into the efficiency changes of different groups separately.

Table 3. 8: Species caught by the three vessel Group

Ranking	PPS		IT		BW	
	Species	weight	Species	weight	Species	weight
1	Norwegian spring herring	45.66%	Norwegian spring herring	33.02%	Blue whiting	46.51%
2	Capelin	21.76%	Sand eel	22.73%	Norwegian spring herring	23.75%
3	Mackerel	15.93%	Blue whiting	12.08%	Capelin	12.78%
4	North sea herring	10.52%	Mackerel	11.05%	Mackerel	8.11%
5	Other	5.86%	Capelin	10.95%	North sea herring	5.50%
6	Blue whiting	0.27%	North sea herring	6.58%	Other	3.34%
7	Sand eel	0.00%	Other	3.59%	Sand eel	0.01%

Note. In this table, all the species are regulated by catching quota except for sand eel and other.

Table 3. 9 presents the basic statistics of the three vessel groups. In the study sample, the number of purse seiners with blue whiting trawlers is the most, the number of pure purse seiners is the second, and the number of purse seiners with industrial trawlers is the least. Table 3. 9 shows that the age of vessels in all groups goes up and down, but the PPS group have the most aged vessels. From 1994 to 2013, the average vessel age of the BW group is slightly lower than the IT group, but the vessel age of the IT group has a larger variation. There was no sudden jump in vessel age or vessel length around the years when the quota transfer policies were introduced into the specific group.

Table 3. 9: Summary of the three vessel groups

Year	PPS #	PPS length	PPS age	IT#	IT length	IT age	BW #	BW length	BW age
1994	14	48.69	31.43	5	42.17	27.80	13	60.89	29.77
1995	22	49.63	33.09	4	41.62	28.50	12	60.10	31.83
1996	27	50.68	34.07	6	42.35	29.67	11	62.78	26.00
1997	22	51.88	38.00	5	42.57	30.80	9	61.80	29.44
1998	29	50.83	33.14	7	43.71	28.29	42	64.03	19.95
1999	31	51.67	30.48	6	43.88	25	28	65.32	15.32
2000	35	53.72	29.37	6	42.45	10	38	66.24	13.39
2001	31	53.91	24.23	8	43.80	16.75	37	66.85	9.92
2002	31	53.97	24.45	9	44.27	15.89	41	66.71	11.27
2003	27	56.53	23.56	8	47.25	14.88	38	67.78	11.55
2004	21	55.77	22.10	7	49.64	11.57	38	67.41	9.55
2005	24	57.05	20.25	7	51.56	13	41	68.34	9.80
2006	22	58.41	18.95	7	52.19	12.71	34	68.47	8.97
2007	24	55.66	19.46	4	57.10	5.5	33	68.36	10.52
2008	19	55.32	23.26	9	56.58	13	42	68.10	10.69
2009	15	53.51	24.93	8	58.59	14.25	42	69.15	11.48
2010	18	56.94	26.44	7	56.88	16	41	68.38	12.80
2011	17	54.61	23	6	55.45	18	39	68.06	13.62
2012	17	56.82	25.12	4	58.93	9.75	34	68.55	13.44
2013	18	56.18	24	7	59.46	8.43	30	69.63	13.33
Average	23	54	26	7	50	17	32	66	16

Figure 3. 7 and Figure 3. 8 depict the technical and allocative efficiency changes in the three vessel groups. Recall that, the efficiency is measured by the cost increased by inefficiencies $(\frac{cost\ with\ inefficiency}{optimal\ cost} - 1)$. That means a higher number on the y-axis refers to a larger cost waste, thus lower efficiency level. The short-run and long-run efficiency trends are similar. First, the PPS group has the highest waste in cost due to inefficiencies, and the BW group does the best in both technical and allocative efficiencies. Second, efficiencies in all the three groups are improving in general, except for the short-run technical efficiency in the IT group. Table 3. 9 shows that the vessel length in the IT group increases the fastest, and Figure 3. 9 suggests that the vessel owners in the IT group change the vessel length most frequently. In other words, the vessel owners in the

IT groups are more willing to bring in larger vessels. It can be expected that larger vessels can catch more fish, but larger vessels also need to hire more labor and consume more fuel. In the short run, when the catching capacity does not match the production plan, any technical efficiency improvement is difficult to achieve. This might be why the IT group's technical efficiency level is lower. Third, the efficiency improvement process in the three groups experience peaks and valleys, and there is no concrete evidence to conclude that the transferable quota policies brought either positive or negative impacts on efficiencies.

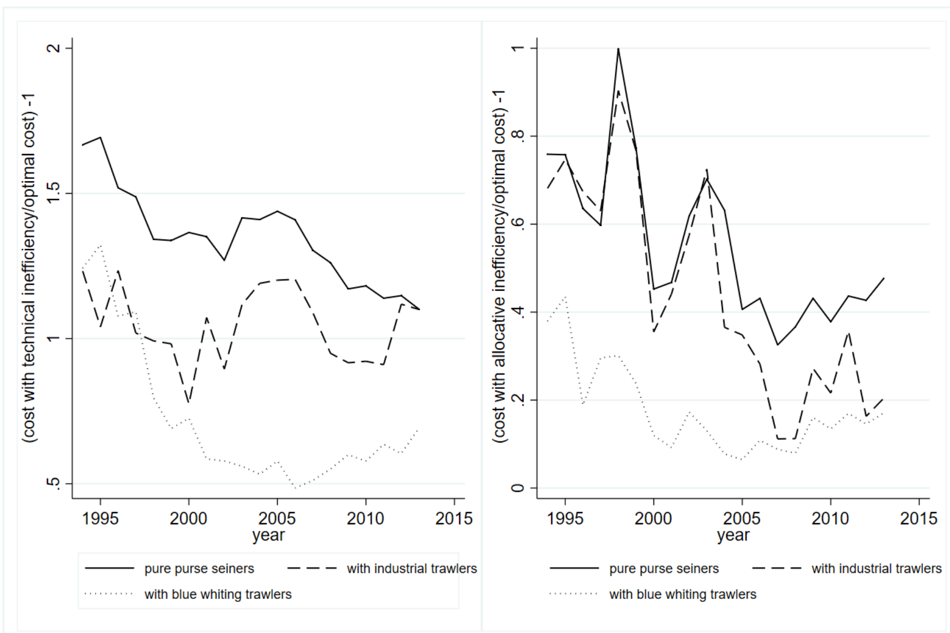

Figure 3. 7: Cost increased by inefficiencies by vessel groups-short run

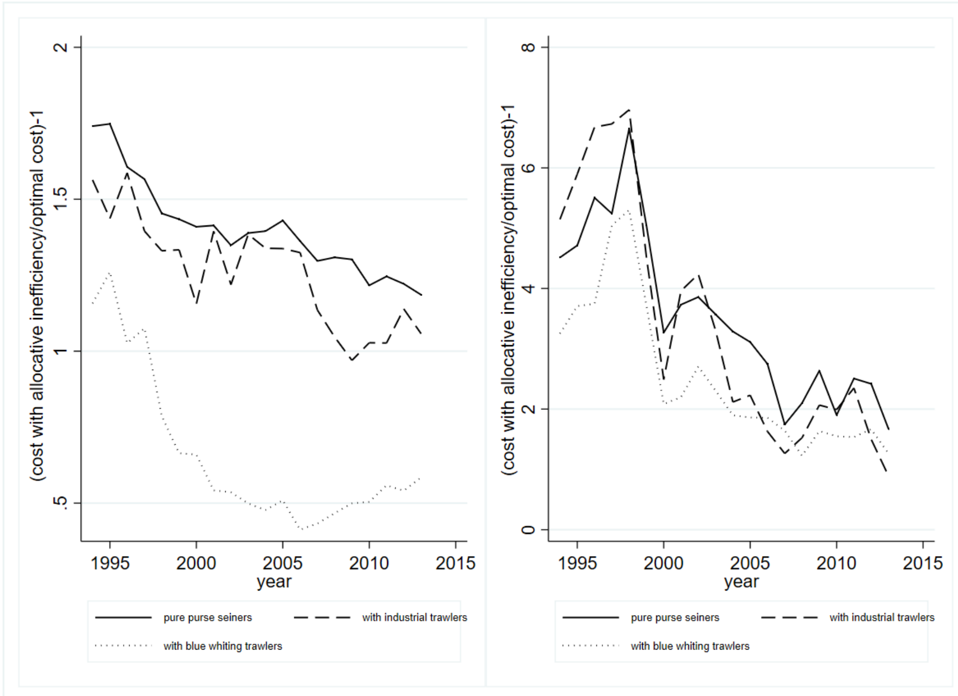

Figure 3. 8: Cost increased by inefficiencies by vessel groups-long run

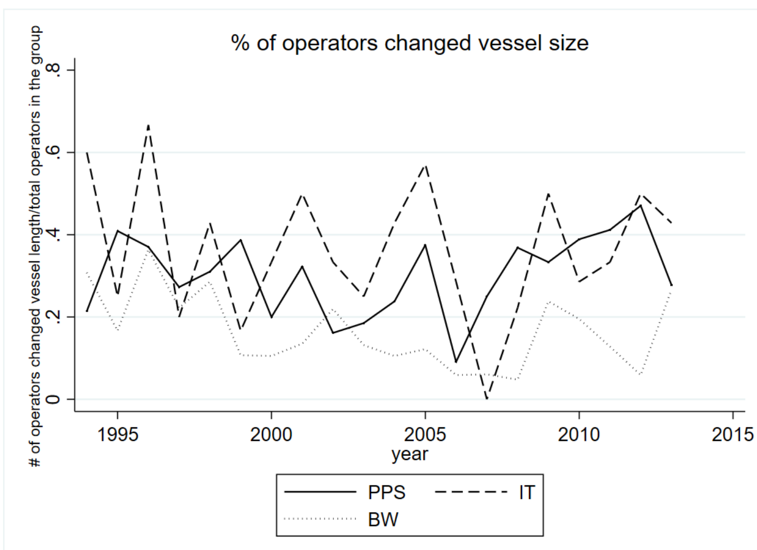

Figure 3. 9: Proportions of vessels change vessel size

When the production level is so low that some resources cannot be utilized to produce, technical inefficiencies occur. Namely, we should be able to observe a mirror relationship between technical inefficiency and the quantity of fish caught by the vessels. This is exactly what is shown in Figure 3. 10. Basically, when vessels catch more fishes, more resources are utilized for production. Therefore, less idle recourses drive down the technical inefficiencies. The variations in catching quantity help to explain, at least in part, the technical efficiency variations, including technical efficiency change in the IT group around 2002 and the change in the BW group after 2006. Moreover, the technical efficiency in the PPS group did not alter its path suddenly around 1996 as the production quantity was in a continuous upward trend. From the above, the technical inefficiency changes are closely related to the production quantity, but it is less likely the results of the transferable quota policies.

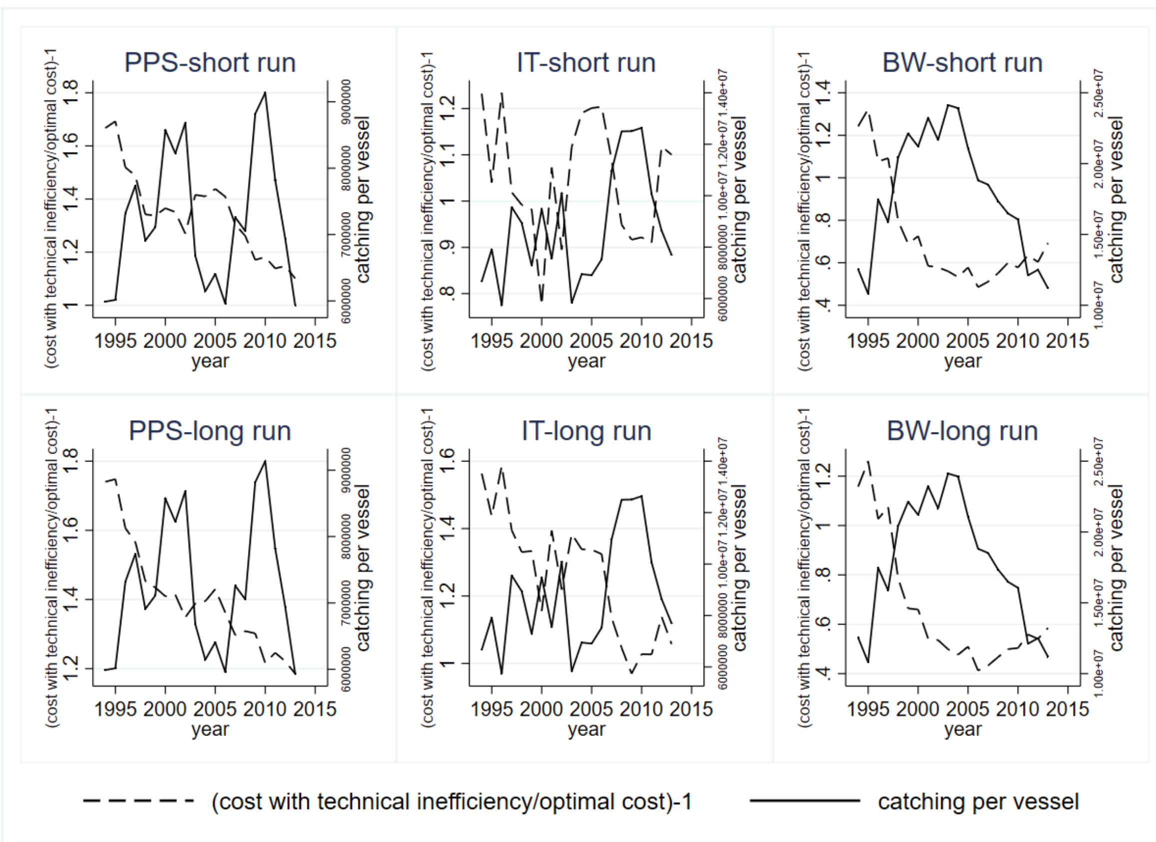

Figure 3. 10: Catching per vessel and technical inefficiency

Allocative inefficiency means inputs are not allocated in the optimal ratio that maximizes the output. Inspired by the definition of allocative inefficiency, the labor cost stands out because the salary paid to the crew is exogenously determined by the fishery associations (Nøstbakken, 2006). Figure 3. 11 suggests that when the salary takes a larger share of the total revenue, the allocative efficiency decreases: labor costs too much. Similarly, when the salary share is lower, the allocative efficiency is higher. Here, labor cost is measured by the actual total salary paid to the crew, and it is a predetermined share of the total revenue of the vessels. The exogenous labor cost means the operators are unable to allocate the input of labor according to the production plan. This explains why the allocative efficiency is inversely related to the salary share. Another evidence indicating the labor cost leads to allocative inefficiencies is in both the short run and long run, labor is overused relative to fuel (Table 3. 5).

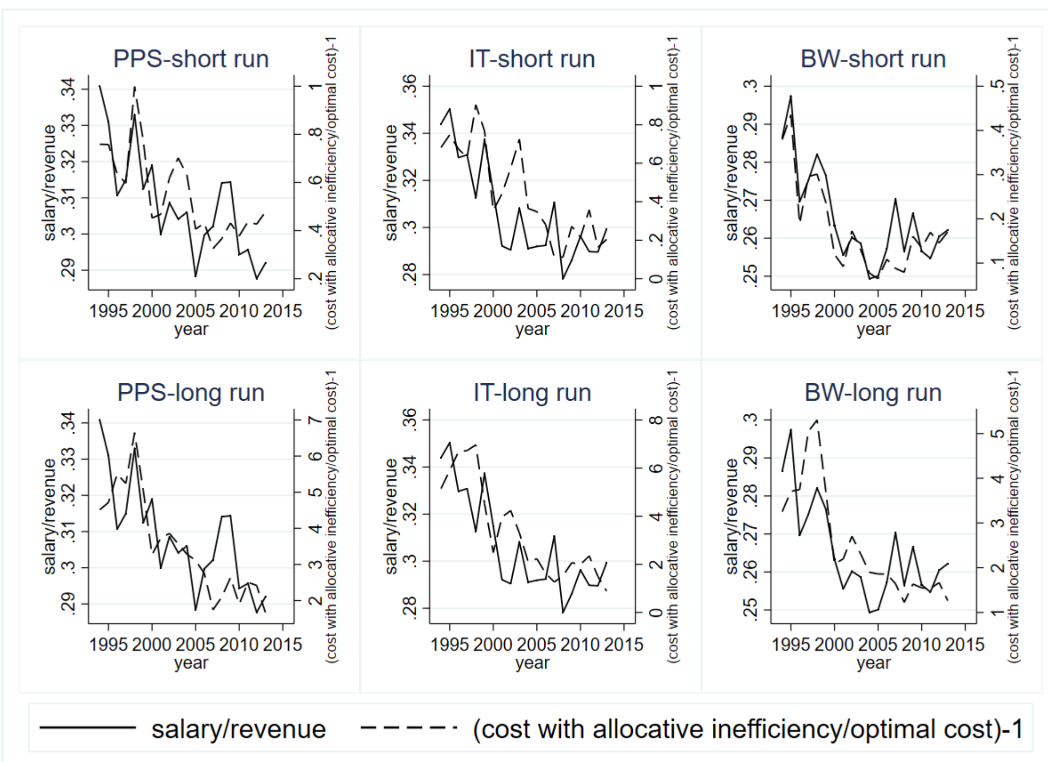

Figure 3. 11: Salary share and cost increased by allocative efficiencies

In addressing the question that whether the policies impact efficiencies, the following two equations are estimated. To identify which factor account for the inefficiencies the most, the variables are standardized before regressing. The standardizing rule is $\frac{variable-mean}{standard\ deviation}$. The standardized coefficients reported in Table 3.10 can be interpreted as one standard-deviation change in the regressor causes β standard-deviation changes in the inefficiency. $D1996, D2002, and\ D2006$ are the dummy variables for the three policy changes; $PPS, IT, and\ BW$ are the dummy variables for the three vessel groups ($BW\ is\ omitted$). Salary share and the catching quantity[9] are also included in the regression because they are found to be influential on efficiencies graphically.

$$\mathrm{inefficiency_{short\ run}} = \alpha + \alpha_1 * \mathrm{salary\ share} + \alpha_2 * \mathrm{y_{regulated}} + \beta_{1996} * \mathrm{D1996} + \beta_{2002} * \mathrm{D2002} + \beta_{2006} * \mathrm{D2006} + \delta_{pps} * \mathrm{PPS} + \delta_{it} * \mathrm{IT} + \gamma_1 * \mathrm{PPS} * \mathrm{D1996} + \gamma_2 * \mathrm{IT} * \mathrm{D2002} + \gamma_3 * \mathrm{BW} * \mathrm{D2006} + \mathrm{t} * \mathrm{year} + \varepsilon$$

$$\mathrm{inefficiency_{long\ run}} = \alpha + \alpha_1 * \mathrm{salary\ share} + \alpha_2 * \mathrm{y_{regulated}} + \beta_{1996} * \mathrm{D1996} + \beta_{2002} * \mathrm{D2002} + \beta_{2006} * \mathrm{D2006} + \delta_{pps} * \mathrm{PPS} + \delta_{it} * \mathrm{IT} + \gamma_1 * \mathrm{PPS} * \mathrm{D1996} + \gamma_2 * \mathrm{IT} * \mathrm{D2002} + \gamma_3 * \mathrm{BW} * \mathrm{D2006} + \mathrm{t} * \mathrm{year} + \varepsilon$$

As discussed, salary paid to the crew is predetermined by fishery associations, where $salary\ share = \frac{salary}{revenue}$. $\gamma_1, \gamma_2, and\ \gamma_3$ measure the policy changes effects on the efficiencies in the specific vessel groups. Inefficiencies are measured as: $\frac{cost\ with\ inefficiencies}{optimal\ cost} - 1$.

[9] Only the species under the regulation of quota were included in this regression. This is because the quantity of these species can be caught is regulated by quota, and they can be considered as quasi-fixed.

Table 3. 10: Efficiency changes and transferable quota policies – standardized coefficient

	Short-run		Long-run	
	Tech. inefficiency	Alloc. inefficiency	Tech. inefficiency	Alloc. inefficiency
salary share	-0.001	0.116*	-0.001	0.201***
Catching quantity	-0.293***	-0.380***	-0.250***	-0.205***
Time trend	-0.018***	-0.033***	-0.012***	-0.090***
D1996	-0.112***	0.185**	-0.069**	0.925***
D2002	0.020	0.164***	-0.003	-0.041
D2006	-0.060***	-0.239***	-0.007***	-0.041
PPS	0.009	0.153	0.023	0.276
IT	-0.088	-0.238	-0.024	-0.115
D1996*PPS	0.049	-0.140	0.021	-0.421
D2002*IT	0.156***	0.243	0.088**	0.043
D2006*BW	-0.091***	0.060	-0.074***	0.101
Constant	36.607***	65.849***	23.825***	179.645***
Fixed effect	Yes	Yes	Yes	Yes
Cluster on vessel	Yes	Yes	Yes	Yes
R-sq (within)	0.542	0.137	0.520	0.191
R-sq (between)	0.531	0.657	0.800	0.602
R-sq (overall)	0.608	0.573	0.812	0.468
Prob>F	0.000	0.000	0.000	0.000
# of observations	1,237	1,237	1,237	1,237

* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.

As shown in Table 3.10, in both the short and long run, the catching quantity is negatively related to inefficiencies and it accounts for the most changes in technical and allocative inefficiencies. Consistent with Figure 3. 11, the allocative inefficiency is positively related to salary share. The significantly negative coefficient of time trend suggests that the total cost waste due to technical and allocative inefficiencies is declining over time. That is, both technical and allocative efficiencies improve over time. Corresponding to the establishment of the Unit quota system (UQS) and the Structure quota system (SQS), the number of vessels has been significantly reduced (Norwegian Directorate of Fisheries, 2019; OECD, 2002). The decreasing number of vessels has at least two effects, both of which can improve efficiencies. First, the quota left by the withdrawn vessels will be allocated to the remaining vessels. Therefore, each vessel can get more fishing quota overtime (Winder, 2018). As the regression results suggest, both the technical and allocative efficiencies are higher when the catching quantity is higher (Column 1, Table 3.10). Second, the vessels with poor efficiency have stronger incentives to sell the quota for money and withdraw from the industry. As the inferiors became fewer, the overall efficiency improves. In addition, expecting that vessel number is decreasing and everyone can get more quota, vessel owners who stay in the industry are confident to invest in larger and newer vessels. This probably explains the robust increase in vessel length, vessel capacity, and the decrease in vessel age.

The quota policies affect the three groups differently (the shaded columns in Table 3.10). Neither the technical nor the allocative efficiency of the pure purse seiners changes significantly after the quota policy is introduced in 1996. The policy regulating the quota transfer in the IT group has no impact on the allocative efficiency while it aggravates the technical inefficiency. The policy does not influence the allocative efficiency of the BW neither, but on average the technical efficiency of the BW group improves after 2006. According to the estimation results, the policies aiming at regulating the additional quota purchases have an insignificant impact on allocative efficiency in all three groups. Moreover, the policy targeting the pure purse seiners has no impact on the pure purse seiners' technical efficiency. The policy changes reduce the technical efficiency in the IT group but promote the technical efficiency in the BW group.

Why do similar policy changes affect BW and IT oppositely? One reason can be different investment strategies. The direct result from the quota transfer policies is some vessels can obtain more quota. Induced by the increased fishing quota, an indirect result of the quota policies is some vessel owners choose to upgrade their vessels. When the upgrade matches the production requirement, it can play a positive impact on technical efficiency. However, when vessels are over upgraded, the technical efficiency could be worse. From Table 3. 9, we know that the BW group have the largest vessels, but during the period of 1994-2013 (Column 8, Table 3. 9), this group does not increase the vessel length very much compared with the other two groups. The less frequent vessel length change of the BW group is also presented in Figure 3. 9 (the dotted line). The 2006 policy enables the vessels in the BW group to receive more fishing quota. The investment on vessels in this group is in a reasonable range that just meet the increased production requirement. Oppositely, vessels in the IT group used to be the smallest, but the vessel length increases fast (Column 5, Table 3. 9) and frequently (dashed line in Figure 3. 9). The 2002 quota policy motivates the vessel upgrade in the IT group as well, but the upgrade in the IT group might diverge from the production need.

In summary, both technical and allocative efficiencies exhibit upward trends over the period. The quota transfer policies might contribute to the efficiency improvement in the way that the vessel number is declining as a result of the policy changes. However, the estimation results reported in Table 3.10 does not provide solid evidence that the policy changes secure an efficiency improvement directly. In addition to the above-mentioned explanations, one more conjecture about why the impacts of the policies are not uniform or robust is the complexity of the Norwegian fishery reforms. The management systems, such as IVQ, UQ, and SQS, were developed gradually and incrementally (Winder, 2018). In addition, the policies were implemented with hesitation, for example, the structural quota system was once paused in 2005 and reopened in 2007 (Norwegian Directorate of Fisheries, 2018). The reform progress could confuse the vessel owners and make it difficult to predict their reactions corresponding to a new policy amendment. Thus, the efficiency changes might be biased to an ambiguous direction by the uncertainties in policies and fishermen’s behaviors. Besides, vessel owners were transferring quotas privately before the quota transfer policies were established. The policies introduced in 1996, 2002, and 2006 only provide a formalized guideline for the vessels owners to obey in future transactions. Therefore, it is not supervising to see that those policy changes did not affect efficiencies largely.

3.8 Conclusions

The stochastic frontier analysis shows that the Norwegian purse seiners can increase production level by 36%-44% by eliminating technical inefficiencies. Moreover, the short-run cost on labor and fuel can be 125% lower if there are no technical or allocative inefficiencies, and the long-run cost can be 1/5 of the current cost level if all the inputs are utilized and allocated efficiently.

The mismatch between the investment on vessels, for instance, the vessel length, and the vessel cargo capacity, and the actual production plan is an important driver for the inefficiencies. Additional investment is beneficial to efficiency only if it meets the production requirement. Overinvestment on vessels leads to idle resources and climbing maintenance expenditure. Therefore, the investment in vessels should be adjusted according to the actual production plan. The exogenously determined labor cost also generate artificial allocative inefficiencies.

We find that vessels above 60m are more efficient than the smaller vessel on average. The technology upgrade and economic scale might explain the higher efficiency associated with the larger vessels. Meanwhile, the larger vessels are also found to catch more and more share of fish, and smaller vessels' catching share is declining. This, once again, highlight that it is the match between vessel size and production level matters with regard to efficiencies. There is no golden rule that a larger vessel is more efficient or smaller vessel can do better.

Despite the existence of inefficiencies, from 1994 to 2013, the Norwegian purse seine fleet improves both technical and allocative efficiencies significantly. Different from the high-level but stable time-varying technical efficiency, the time-invariant technical efficiency exhibits a robust increasing trend. The management skills of the vessel operators, the working skills of the fishermen, and the technology improvement over time can all explain the efficiencies.

The introduction of the transferable quota policies among the three vessel groups does not generate a uniform efficiency change. The unclear impact of the policy changes might be due to the fact that the private quota transfers between vessels were acquiesced even before the policies were implemented. Meanwhile, the complication of the Norwegian fishery reforms could play a role as well.

Although inefficiencies cause moderate cost waste in the Norwegian purse seine fleet, a clear efficiency improvement pattern is identified. As the rights-based management system reduces the number of vessels, it also reshuffles the vessel structure. Less efficient vessels and fishermen withdraw from the industry, and the remaining fishermen operate the upgraded vessels in a more efficient way. However, the vessel investment decision needs to base on the production requirement in order to realize the best efficiency result.

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