How multi-tasking job designs affect productivity? Evidence from Australian Open Cut Coal Mines

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Abstract

After the late 1980s, Australian coal mines vigorously pursued two types of multi-tasking: (I) multi-tasking between production stream and engineering stream tasks and (II) multi-tasking within the production stream. Using an original panel data covering the period 1985 to 2005, I test three existing theories about how multi-tasking job designs affect productivity: *control of incentive* (bundling of tasks with similar performance-measurability makes a performance pay more effective), *redundancy elimination* (bundling of 'overlapping' tasks eliminates duplication of effort and setup time), and *adaptiveness* (task bundling makes a firm more adaptive to a changing environment). The results strongly support redundancy elimination theory. Only when overlapping tasks are bundled together (type I multi-tasking), does multi-tasking enhance productivity. While type I multi-tasking would increase coal production by 33%, the effect of type II multi-tasking is nonexistent. The control of incentive theory is rejected as bundling of tasks with similar performance-measurability (type II multi-tasking) does not enhanced productivity. I do not find conclusive evidence supporting adaptiveness theory, as the association between coal demand uncertainty and the adoption of multi-tasking is weak. It is not multi-tasking itself but specific task contents of multi-tasking that are important. In particular, bundling of overlapping tasks most effectively enhances productivity.

1 Introduction

Growing body of literature documents the trend that work organizations have shifted away from Tayloristic organization characterized by specialization towards more flexible work organizations, involving multi-tasking job designs with less specialized task assignment.

Multi-tasking is a situation where workers are capable of performing several tasks, and may be performing these tasks with some regularity (Lazear 1998). Extensive evidence suggests that the use of multi-tasking job design is widespread. Ichniowski (1992) and Adler et al. (1995) contain case evidence showing that firms have significantly reduced the number of job classifications. Multi-tasking is often achieved by job rotation. Using 694 manufacturing establishments in the US, Osterman (1994) shows that nearly 50% of his sample has adopted some form of job rotation. Lindbeck and Snower (2000) present evidence that European firms are also moving toward multi-tasking work organizations, while similar evidence from Korea is presented by Park (1996).

The recent widespread use of multi-tasking indicates that the adoption of multi-tasking job design is motivated by its possible productivity-enhancing effect. Yet, past literature has not provided sufficient answers to the following two questions. The first question is, *what is the productivity-enhancing effect of multi-tasking?* Katz et al. (1987) examine the effect of multi-tasking job design, such as reduced job classification, on plant-level productivity of a large US automobile producer, but they find that adoption of multi-tasking has no effect on productivity. Cappelli and Newmark (2001) find that job rotation has a negative effect on productivity (See Table 3 of their study). Other studies have focused on complementarities among different human resources practices. One often-employed empirical strategy is to construct a binary variable that shows the existence of a pre-determined human resource bundle, rather than entering the products of different work practice variables into the model[1]. Such an empirical strategy makes

[1] Ichniowski et al. (1997) and Macduffie (1995)

it difficult to assess the individual impact of multi-tasking. Thus, the individual impact of multi-tasking on productivity has not been well-established.

The second question is, *what is the mechanism through which multi-tasking job designs affect productivity?* Although there are several studies that examine why some firms adopt 'flexible work practices' while other firms do not (Osterman 1994; Ichniowski and Shaw 1995; Gittleman et al. 1998; Gale et al. 2002), these studies do not test existing theories about how multi-tasking would affect productivity.

In this paper, I attempt to answer both of the aforementioned questions by using an original data set of Australian open cut coal mines covering the period 1985 to 2005. After the bargaining system was decentralized in the late 1980s, the Australian coal mines vigorously eliminated two types of task demarcation: (I) task demarcation between production stream tasks (equipment operation tasks) and engineering stream tasks (equipment maintenance tasks), and (II) task demarcation within the production stream tasks (tasks associated with different types of equipment).

To answer the second question: *what is the mechanism through which multi-tasking job designs affect productivity*, I test three existing theories. First, I consider *control of incentive theory*. Holmstrom and Milgrom (1991) show that, under principal-agent setting, a job design that bundles tasks with similar performance-measurability enables the principal to provide a performance pay without fearing that the agent would sacrifice hard-to-measure activities. A better control of incentive would translate into higher productivity. Second, I consider *redundancy elimination theory*, derived from Lazear

(1998, p.450). A task generally consists of a series of subtasks. When two tasks share a common subtask which can be performed by the same worker at the same time (when there is a 'task overlap' in my term), bundling of the two tasks eliminates the duplication of effort and unnecessary setup time. Third, I consider *adaptiveness theory*. Dessein and Santos (2006) show that the ability of an organization to adapt to a changing environment increases with task bundling. Greater adaptiveness would translate into higher productivity.

To preview the results, my empirical results most strongly support the redundancy elimination theory. In the redundancy elimination theory, the presence of a task overlap is essential for the productivity-enhancing effect of multi-tasking. I show that a task overlap exists *between* the production and engineering stream tasks, but not among the tasks *within* the production stream. Consistent with the redundancy elimination theory, I have found a large productivity gain from eliminating the task demarcation between production and engineering streams, but not from eliminating task demarcation within the production stream. After controlling for fixed effects and year effects, and holding constant employment, equipment and all the changes in other work practices, elimination of task demarcation between production and engineering streams would increase the saleable coal production by 31% to 33%. In contrast, the effect of the elimination of task demarcation within the production stream is small and statistically insignificant.

The control of incentive theory is rejected. While the performance of production stream tasks can be easily measured by the amount of coal and overburden[2] excavated

[2]Earth covering the coal seam

and removed by the equipment, the performance of engineering stream tasks is more difficult to measure since the quality of the maintenance work is difficult to measure. On contrary to the prediction of control of incentive theory, I find that bundling of tasks with similar performance-measurability (elimination of task demarcation within the production stream) has no impact on productivity, while bundling of tasks with different performance-measurability (elimination of task demarcation between the production and engineering streams) significantly enhances productivity.

This study does not find conclusive evidence supporting the adaptiveness theory. A theoretical implication of adaptiveness theory is that the adoption of multi-tasking is positively associated with the uncertainty of business environment. Mines with lower coal quality face greater likelihood that their coal is purchased in the spot market rather than on a long term contract. I use several coal quality variables as the proxies for coal demand uncertainty. Although the coefficients for many coal quality variables show the expected sign (i.e., lower coal quality is associated with higher adoption of multi-tasking), there are several cases where the coefficients show the opposite sign. The evidence is not strong enough to conclusively support the adaptiveness theory.

The results show that a multi-tasking job design has a significant productivity-enhancing effect in Australian coal mining industry, and that such productivity gain has been realized through the elimination of redundancy stemming from the bundling of 'overlapping' tasks. It is not multi-tasking itself but the task contents of multi-tasking that are important. In particular, multi-tasking job design most effectively enhances productivity when overlapping tasks are bundled into one job.

This paper is organized as follows. Section 2 summarizes the theoretical background, then derives testable implications; section 3 summarizes background information and explains how the multi-tasking variables are constructed; section 4 describes the data; section 5 outlines the estimation methods, section 6 shows the empirical results, and section 7 concludes.

2 Theoretical backgrounds

Control of incentive theory Earlier literature on multi-tasking focuses on how an incentive contract should be made in a principal-agent setting when the agent undertakes multiple tasks (Holmstrom and Milgrom 1991; Homstrom and Milgrom 1994; Slade 1996). When performance of some tasks is not easily measured, a performance pay may cause the agent to sacrifice hard-to-measure activities. To mitigate this problem, Holmstrom and Milgrom (1991) show that (i) the principal should bundle tasks whose performance is most easily measured into one job, with remaining tasks into another, then (ii) the principal should provides higher 'commission rate' to the job holder whose performance is easy to measure. Since hard-to-measure activities are separated in this job design, the principal has a better control of incentive; the principal can provide a performance pay without fearing that the agent would sacrifice hard-to-measure activities. A better control of incentive would translate into higher productivity.

Redundancy elimination theory Lazear (1998, p.450) shows that multi-tasking would enhance productivity through elimination of redundancy. A task consists of a series of subtasks. When two tasks share a common sub-task which can be performed by the same worker at the same time (when there is a 'task overlap', in my term), bundling of the two tasks eliminates a duplication of effort. Moreover, bundling of the two tasks eliminates the need to pass the common subtask to another worker, which in turn eliminates the need for another worker to make a trip to perform the task, reducing setup time. Thus, bundling of 'overlapping' tasks would enhance productivity through the elimination of redundancy arising from the duplication of effort and unnecessary setup time.

Adaptiveness theory Dessein and Santos (2006) consider a setting where the goal of an organization is to adapt to a changing environment, but information needed to do so exclusively pertains to a particular task and can be observed only by the worker who undertakes the task (information is local). If a worker wants to adjust his/her action to such local information, he/she has to communicate with other workers to inform about such adjustment. Since communication is not perfect, adapting 'too much' to local information may cause coordination failure. Thus, the degree to which workers can tailor their actions to local information is constrained by the coordination cost. The coordination cost can be reduced by increasing the number of tasks to be bundled into one job, since coordination is perfect among tasks that are performed by the same worker. Thus, an organization can be more adaptive to a changing environment by increasing task bundling. Greater adaptiveness would translate into improved productivity.

2.1 Testable implications

As will be detailed in the subsequent sections, the Australian coal mining industry vigorously eliminated two types of task demarcation: (1) tasks demarcation between production stream tasks (equipment operation tasks) and engineering stream tasks (equipment maintenance tasks), and (2) tasks demarcation within the production stream tasks (tasks associated with different types of equipment). To develop testable implications of the theories, consider the following production function to estimate the effects of the two types of multi-tasking on productivity.

$$\begin{aligned} \log(Output)_{it} &= \beta_1(MultTask\_Between)_{it} + \beta_2(MultTask\_Within)_{it} \\ &+ \alpha' Z_{it} + c_i + \mu_{it} \end{aligned} \quad (1)$$

where i denotes the mine and t denotes the time. The variable, (MultTask_Between), represents the elimination of task demarcation between the production and the engineering stream tasks. The variable, (MultTask_Within), represents the elimination of task demarcation within the production stream. The variable, Z, would include employment, equipment usage, geological conditions, other work practice variables, and year dummies. The term, c_i, is the mine specific fixed effect.

2.1.1 A testable implication for the control of incentive theory

The control of incentive theory indicates that multi-tasking would be productivity-enhancing when tasks whose performance is easy to measure are bundled into one job, with remaining tasks into another. Thus, let us consider the performance-measurability of production stream and engineering stream tasks. Production stream tasks entail the operation of various types of equipment, such as power shovels, trucks, and bulldozers. Performance of production stream tasks can be easily measured by the amount of coal and overburden excavated and removed by the equipment. In contrast, performance of engineering tasks is more difficult to measure since quality of maintenance is difficult to measure. Therefore, the control of incentive theory indicates that (i) the productivity-enhancing effect of the multi-tasking between production and engineering stream would be *limited* since this job design bundles tasks with different degree of performance-measurability, but that (ii) the multi-tasking within the production stream would enhance productivity since this job design bundles only tasks whose performance is easy to measure. The testable implication for the control of incentive theory is the following.

- **Implication 1**: The effect of (MultTask_Between) would be close to zero, while the effect of (MultTask_Within) would be positive.

2.1.2 A testable implication for the redundancy elimination theory

Redundancy elimination hypothesis indicates that multi-tasking would improve productivity if 'overlapping' tasks are bundled together. First, let us examine whether there is a 'task overlap' between production and engineering tasks. The engineering workers undertake maintenance tasks such as fixing electrical problems. On one hand, an engineering task would first involve inspection of equipment to identify mechanical problems, then making repairs. On the other hand, production tasks involve the operation of equipment. Notice that, by operating equipment, it is relatively easy for the production worker to identify possible mechanical problems because operating the machine is one way to inspect the machine. Thus, a task overlap exists between production and engineering tasks in a sense that there exists a common sub-task; that is, to inspect and identify mechanical problems. Once the production workers identify a mechanical problem, fixing the problem as well would eliminate redundancy arising from having the engineering worker inspect the machine one more time. If the production worker fixes the problem, it also saves the time waiting an engineering worker to arrive at the site. However, this was precisely what mines were prohibited from doing. Exxon Coal (1997) notes that, because of strict task demarcation, even if a production worker found a simple mechanical problem, a worker from engineering had to be called for the maintenance, resulting in considerable loss of production time.

Second, let us investigate the existence of a task overlap among the tasks within the production stream. Consider the following two tasks within the production stream, power shovel operation and truck driving. A power shovel operator excavates coal, then loads the coal onto a truck. A truck driver delivers the coal to the coal washery facility. The task of power shovel operation consists of two subtasks: extracting coal from the coal seam, then loading the coal onto the truck, both of which are clearly not a part of the truck driver's task. Thus, there is no task overlap between the power shovel task and the truck driving task. For example, if the same worker operates both a power shovel and a truck, the worker has to load the coal onto the truck, then drive the truck to deliver the coal. This would not eliminate any redundancy. The absence of task overlap appears to be true among different combinations of tasks within production stream (i.e., between power shovel operation and bulldozer operation).

The above discussion implies that (1) multi-tasking between production and engineering streams increases productivity due to the presence of a task overlap while (2) the productivity-enhancing effect of multi-tasking within the production stream is limited. The testable implication for the redundancy elimination theory is,

- **Implication 2**: the effect of (MultTask_Between) would be positive while the effect of (MultTask_Within) would be close to zero.

Note that this implication is opposite to the prediction of control of incentive theory.

2.1.3 A testable implication of the adaptiveness theory

Adaptiveness theory is silent regarding which tasks should be bundled into one job in order for multi-tasking to increase adaptiveness. I use one theoretical implication of the adaptiveness theory. Dessein and Santos (2006) show that when firms optimally choose the number of tasks to be bundled into one job, the optimal task bundling is increasing with the uncertainty of business environment. I use several coal quality variables as proxies for coal demand uncertainty. Coal quality is measured by the amount of impurities contained in the coal, such as ash, moisture, volatile matters and sulphur. The greater the impurity contents, the lower the coal quality. Although much of the

Australian coal is purchased on long term contracts, coal that does not meet quality standards set by long term contracts is more likely to be purchased in the spot market (Productivity Commission 1998b, p.D15). Thus, mines with low coal quality face greater demand uncertainty. A testable implication for the adaptiveness theory is,

- **Implication 3**: Mines with lower coal quality (i.e., greater impurity contents) are more likely to employ both types of multi-tasking.

3 Australian open cut coal mining industry: Background

3.1 Task demarcation in the Australian coal mining industry

The open cut mining method involves removal of the earth above the coal seam. Coal mining generally requires two streams of tasks: production and engineering streams. Workers in the production stream operate various types of equipment. Workers in the engineering streams maintain the equipment. In Australia, there was strict task demarcation *between* production and engineering streams. Furthermore, there was strict task demarcation *within* the production stream based on the type of equipment a worker operates. Task demarcation has been considered by the mine managers as a major factor restricting the productivity of Australian coal mines. Exxon Coal (1998) notes that "Australian coal mines fall well short of best practice productivity levels achieved by comparable international coal mines ... There are a significant number of factors which contribute to this result... Among other things, this include demarcation of work..."

Task demarcation in Australian coal mining industry arose, historically, due to different union coverage (Barry et al. 1999), and had become deeply entrenched in its workplace due to (i) union opposition to the change in demarcation rules and (ii) P&E Award[3], a multi-employer collective bargaining agreement that covered almost all of the coal mines in the State of New South Wales (NSW) and Queensland (QLD) during 1990s.

P&E Award entrenched task demarcations in the following ways. First, the P&E Award provides a legal basis to task demarcation *within* the production stream. The P&E Award classifies production stream tasks into 9 categories based on the equipment type and capacity. The narrowly defined job classifications entrenched task demarcation within the production stream. Second, the P&E Award provides a legal basis for the demarcation *between* production and engineering streams. Clause 31 of the P&E Award, known as 'customs and practices' provision, gives informal work practices a legal status. Thus, Clause 31 provides a legal basis to the demarcation between the streams simply because it has been a common practice in the coal mining industry. Nonetheless, the industry gained the opportunity to eliminate task demarcations when the bargaining system was decentralized in the late 1980s.

3.2 The opportunity for multi-tasking

Starting from late 1980s, Australian bargaining system was significantly decentralized. First, Industrial Relations Act 1988, Industrial Relations Reform Act 1993 and Work

[3]P&E Award: the Australian Coal Mining (Production and Engineering) 1990 Interim Consent Award

Place Relations Act 1996 came into practice, allowing mines to opt out of the P&E Award. More specifically, these acts allowed a mine to negotiate a mine-specific collective agreement with its employees so that the mines can alter the P&E Award conditions. Second, the P&E Award included Clause 20 in 1990, which allowed mines to alter the the P&E Award conditions by negotiating mine-specific collective agreements. Mine-specific collective bargaining agreements are called '**enterprise agreements**' in order to emphasize the fact that the agreements are negotiated at an enterprise level, not at an industry level.

Enterprise agreements presented mines with the opportunity to eliminate demarcation rules: they allowed mines to alter the conditions of the P&E Award that entrenched task demarcations. It also allowed mines to facilitate multi-tasking by explicitly stating, in the enterprise agreement, that each worker is required to multi-task. Next section examines exactly how the enterprise agreements eliminated task demarcations.

3.3 How enterprise agreements have eliminated demarcations

3.3.1 Elimination of demarcation within the production stream

The elimination of demarcation within the production stream was accomplished by the negotiation of a 'work model'. Due to mounting criticism by coal managers concerning the perceived inefficiency of Australian coal mines in the late 1980s, the P&E Award introduced the 'work model' provision. The work model provision allows a mine to reduce job classifications by negotiating a work model with its employees. A work model typically specifies a list of core skills, such as excavator operating skills. Then, jobs are classified into several levels based on the number of skills a worker possesses, with each level being given a different wage rate. A work model has to be approved by the Coal Industry Tribunal in the form of enterprise agreement [4]. The number of job levels to be set in a work model is up to the negotiation at each mine. Once the work model is approved, a worker can be assigned to any tasks within his/her level, even on short notice (Barry et al. 1999). A job design with fewer job level provides mine managers with greater multi-tasking capability. This point has been made in several enterprise agreements. Bloomfield Colliery's 1992 enterprise agreement reduced its job classification to 5 levels, noting that "[t]his relatively flat wage structure (thus fewer job levels) will enable employees to be involved in a broad range of tasks...(Clause 9.2)".

3.3.2 Elimination of demarcation between production and engineering streams

The elimination of demarcation *between* production and engineering streams was achieved separately from the elimination of the demarcation *within* the production stream due to one stipulation in the work model. The work model guideline explicitly divides jobs into production and engineering streams. This means that if a mine employs a work model (to eliminate demarcation *within* the production stream), the demarcation *between* production and engineering streams will be automatically entrenched. To eliminate the demarcation between production and engineering streams, mines had to further negotiate with their employees to include a provision that explicitly eliminates the demarcation between the two streams. For example, the Stratford Mine's 2002 enterprise agreement

[4] The Coal Industry Tribunal is one branch of the Industrial Relations Commissions, the industrial tribunals in Australia.

explicitly states that "...there will be no demarcation of work between production and engineering (Clause 3)".

3.4 The construction of multi-tasking variables and other work practice variables

Based on the discussions in the previous section, a reasonable variable that represents the elimination of the demarcation ***within*** the production stream is the reduction in the number of job classifications. The maximum number of job classifications is nine as given by the P&E Award standard job classifications. Thus, I define a variable, (ClassRedu), by

- **(ClassRedu)** = 9 – (the # of job classifications in the enterprise agreement)

(ClassRedu) captures the effect of the multi-tasking ***within*** the production stream. Therefore, (ClassRedu) is the variable that corresponds to (MultTask_Within) in the equation (1) of Section 2.1.

I constructed a binary variable, ($MultTask\_Between$) that attempts to show a genuine elimination of demarcation between production and engineering streams by using the following three criteria.

- **(MultTask_Between)** =1 (1) if the mine explicitly requires production and engineering workers to multi-task across the streams, (2) if the mine eliminates the distinction between production and engineering work, and at the same time, explicitly requires an employee to undertake any tasks that are allocated by the employer, or (3) if the mine allows a production and engineering workers to cross train their core skills, such as truck driving, or excavator operations. If neither (1), (2) nor (3) holds, this variable takes the value 0.

Other work practices: In order to separate the effect of multi-tasking from other changes in work practices, I examined enterprise agreements to find all other changes in work practices that would affect productivity. Table 1 shows the definition of each work practice variable.

4 The data

4.1 Data sources

Multi-tasking variables and other work practice variables are constructed by examining the enterprise agreements. Since equipment data is only available for the mines in NSW, enterprise agreement data collection was confined to the mines in NSW. All the enterprise agreements certified after 1996 are available online[5]. Enterprise agreements that were certified before 1995 are obtained from the Australian Industrial Registry. The total number of enterprise agreements used in the study is 97. Production and employment data are provided by Coal Service Pty Ltd.

Open-cut coal mining method uses three types of equipment, (1) excavating equipment, (2) bulldozers, and (3) trucks. I construct input variables corresponding to each type of equipment. Table 2 shows the definitions. NSW Coal Industry Profiles and

[5] http://www.wagenet.gov.au

Coal Year Books contain yearly information about the product number of equipment as well as the number of pieces of equipment used by each mine[6]. Construction of input variables requires capacity information for each equipment. This is obtained by directly contacting the equipment manufacturers, or via the manufacturers' home page.

Data collection is confined to the mines that have operated at least some years during the 1990s since this is the period in which drastic changes in the bargaining system occurred. Some of the mines opened after 1985, the beginning of the sample period. I dropped the first two years of observations, assuming new mines do not immediately reach 'normal' operating conditions. Since the NSW Coal Industry Profile was not published in 1987-1988, these years are not included in our sample. The final sample contains 286 mine-year observations, containing 21 open cut mines during the period 1985 to 2005. Table 3 contains the descriptive statistics.

It is worth noting the size of the sample. The number of observations, 286, may appear to be rather small. Nevertheless, my sample counts, on average, 84% of all the open cut coal production in NSW for our sample period. A small number of cross-sectional units appears to be inevitable for an industry specific research. For example, in the study of the productivity effect of human resources bundles in the US steel plants, Ichniowski et al. (1997) used 35 cross-sectional units over 5-years periods.

[6]For example, these reports may show that a particular mine has 3 pieces of Catapillar D11. Caterpillar D11 is a large size bulldozer.

4.2 Trends in multi-tasking and other work practices

Figure 1 shows the sample average of the work practice variables by year. There is a significant reduction in the number of job classifications within the production stream. By 2001, the sample average of (ClassRedu) is close to 6. Since a mine usually differentiates induction level jobs from ordinary jobs, the maximum (ClassRedu) is 7. This means that most of the mines have significantly eliminated task demarcation within the production stream. The elimination of task demarcation between the streams appears to have been a slow process. Only 30% of the mines eliminated the demarcation between the streams by 2002. Nonetheless, by year 2005, nearly 70% of the mines eliminated such demarcation.

5 Estimation methods

5.1 The production function estimation

Our basic model has been already outlined in section 2.1. This section provides the specifics. The basic model is a log linear production function with mine specific fixed effect. The multi-tasking and other work practice variables are assumed to affect the intercept of the production function. The model is written as

$$\begin{aligned} log(Output)_{it} &= \alpha' X_{it} + \qquad (2) \\ &+ \beta_1 (MultTask\_Between)_{it} + \beta_2 (ClassRedu)_{it} \\ &+ \gamma' (Other\ Work\ Variables)_{it} \\ &+ \theta' (Foreign\ Ownership\ Variables)_{it} \end{aligned}$$

$$+ \quad \eta_1(t) + \eta_2(t)^2 + \eta_3'(Year\ Dummies) + c_i + \mu_{it}$$

where i denotes the mine, and t denotes the time period. The variable, (ClassRedu) corresponds to (MultTask_Within) in equation (1). The vector of variables X_{it} includes the logarithms of employment, equipment variables, and the thickness of the seams. A thinner seam would negatively affect the output. The coefficient, β_1, captures the effect of multi-tasking *between* production and engineering stream tasks while β_2 captures the effect of multi-tasking *within* the production stream. The vector of coefficients, γ, captures the effect of the changes in other work practices. Some mines were owned by foreign companies, notably the Oil Majors[7] and Japanese companies. To capture a possible managerial inefficiency (or efficiency) of these foreign companies, I include Oil-Major ownership, Japanese ownership and their squares in the model. Productivity may increase overtime due to unobserved technological changes. To capture such effects, I include time trend variable t and its square. To control for year specific productivity shocks, I include year dummy variables. The term, c_i, is a mine specific time invariant unobserved effect that would affect coal production. A possible correlation between c_i and other explanatory variables causes biases in the ordinary least square estimation (OLS). Thus, we apply the fixed effect estimation to this model.

5.2 Instrumental variable estimation using coal qualities

If there is a time varying unobserved effect that affects both production and the multi-tasking variables, fixed effect estimation of β_1 and β_2 could be still biased. A possible

[7]Shell, BP, Exxon and Esso

time varying unobserved factor is the level of absenteeism at each mine. Productivity Commission (1998a) reports that Australian mines suffer a high incidence of absenteeism. When the level of absenteeism is high, multi-tasking is more useful (Lazear 1998, p.114). Thus, multi-tasking may be correlated with the level of absenteeism. At the same time, absenteeism would directly affect the production level. I address this issue by using instrumental variable estimation. Valid instruments should be correlated with multi-tasking variables but not with a time varying unobserved effect such as absenteeism.

The main instrumental variables are the coal quality variables and distance to the nearest port, listed in Table 2. Coal qualities are measured by the impurity contents of the coal. As the adaptiveness theory predicts, mines with low coal quality may be more likely to adopt multi-tasking. Also, the greater the train distance, the greater the transportation cost. If multi-tasking saves cost, greater distance may lead to adoption of multi-tasking. It is unlikely that coal quality or the distance have direct impacts on the level of absenteeism. Table 3 shows the descriptive statistics of our instrumental variables. Coal quality and train distance data are derived from the NSW Coal Industry Profiles and the Coal Year Books. We instrument the demeaned multi-tasking variables with demeaned instrumental variables in the two stage least square (2SLS) procedure.

To check the quality of the instruments, I conduct (i) a test for the irrelevance of excluded instruments, (ii) standard NR^2 overidentification restrictions test and (3) Hausman test for endogeneity (Hauseman 1983).

5.3 Estimation of the effect of coal quality on the adoption of multi-tasking job design

Adaptiveness theory is tested by examining the effect of coal quality on the likelihood of adopting multi-tasking. Logit model is used to estimate the effect on the adoption of multi-tasking between production and engineering streams while OLS is used for the adoption of multi-tasking within the production stream. I estimate the following two equations separately.

$$y^*_{it} = \rho'_1(Coal\ Quality\ Variables)_{it} + \phi'_1 Z_{it} + \mu_{it} \tag{3}$$

$$(MultTask\_Between) = 1\ if\ y^* \geq 0,\ (MultTask\_Between) = 0\ if\ y^* < 0$$

$$(ClassRedu)_{it} = \rho'_2(Coal\ Quality\ Variables)_{it} + \phi'_2 Z_{it} + \epsilon_{it} \tag{4}$$

where μ_{it} are assumed to follow a standard logistic distribution. The coefficients, ρ_1 and ρ_2, show the effect of coal quality on the adoption of 'between' and 'within' multi-tasking respectively. The vector of variables, Z_{it}, includes variables that directly affect the adoption of multi-tasking. The past literature on the adoption of 'flexible work practices' has included as explanatory variables, complementary work practices (Osterman 1994; Pil and Macduffie 1996), firm size (Osterman 1994), and other firm characteristics. Guided by these past studies, I include in Z_{it} all the work practice variables listed in Table 1 to control for complementary work practices, employment and equipment variables to control for mine size. I also include thickness of seams, train distances, year dummies, and the time trend variables to control for other firm characteristics, year effects, and a possible time trend in the adoption of multi-tasing. In other words, both equations contain all the variables that are treated as exogenous in the 2SLS estimation of the production function (equation 2).

6 Estimation results

6.1 Checking the quality of instruments and exogeneity

The null hypothesis that the coefficients for the instruments are jointly equal to zero is rejected for both (MultTask_Between) and (ClassRedu) at the 5% significance level (F statistics are 7.3 and 5.3 respectively). Thus, we have rejected the irrelevance of instruments. Estimated coefficients are shown in Table 6 (see, fixed effect models).

Table 4 presents the test statistics for overidentification and exogeneity tests. Notations for the tests follow Wooldridge (2002, p.119-123). The overidentification test statistic is $NR^2 = 6.5$ with the number of exclusion restrictions equal to 10. Thus, we fail to reject the overidentifying restrictions at the 5% significance level. This means that the choice of instruments is correct. As for the exogeneity test, the estimated ρ_1 and ρ_2 are not statistically significant at the 10% significance level. We fail to reject the exogeneity of the multi-tasking variables. Thus, a simple fixed effect model as given by equation (2) turned out to be the most preferable model.

6.2 Individual effects of multi-tasking on productivity

Table 5 presents the estimation results of the basic fixed effect model along with the results of 2SLS and OLS regressions. Fixed effect coefficient for (MultTask_Between) is virtually the same as the OLS estimate. However, the coefficient for (ClassRedu) drops from 0.055 to 0.022 when fixed effect is controlled for, a nearly 60% drop in coefficient. The estimated effects of multi-tasking for 2SLS model deviate considerably from that of fixed effect model. Since the endogeneity of multi-tasking variables is rejected, the interpretation of the results is based on the fixed effect results.

Based on the fixed effect model, multi-tasking ***between*** production and engineering streams has a significant impact on the productivity. After controlling for the fixed effect, and holding constant all other variables, an elimination of demarcation between the production and engineering streams increases saleable coal production by as much as 31%. This effect is surprisingly large when compared to past studies concerning multi-tasking. Katz et al. (1987) did not find evidence that multi-tasking job design, such as reduced job classification, would enhance productivity. Ichniowski et al. (1997) found that job rotation alone had almost no effect on productivity (See Table 7 of their study). Cappelli and Neumark (2001) found that job rotation had a negative effect on productivity (See Table 3 of their study). In other past studies, multi-task variables are often reduced into one component of larger human resource bundles (Ichniowski et al, 1997; Macduffie, 1995), which makes it difficult to infer an individual effect of multi-tasking on productivity. Thus, my result provides fresh evidence that multi-tasking alone has a large impact on productivity.

I did not find evidence that elimination of demarcation ***within*** the production stream increases productivity. Although the sign of the coefficient for (ClassRedu) is positive (0.022), it is not statistically significant at any of the conventional significance levels.

6.3 How multi-tasking enhance productivity? Testing theories

The redundancy elimination theory implies that the effect of (MultTask_Between) would be positive while the effect of (ClassRedu) would be close to zero (see Section 2.1, Implication 2). Therefore, strong effect of (MultTask_Between) coupled with insignificant effect of (ClassRedu) support the redundancy elimination theory. It is worth noting that, prior to the period where multi-tasking became widely used, many mine managers in Australia expressed a major concern that task demarcation between production and engineering stream had created significant losses in production time (Productivity Commission, 1998a). Thus, the results show that mine managers concern was indeed valid.

The control of incentive theory is rejected. My results are contrary to the implication that the effect of (MultTask_Between) would be close to zero while the effect of (ClassRedu) would be positive (see Section 2.1, Implication 1). The control of incentive theory indicates that productivity gain is realized by providing *higher* 'commission rate' for the job holders whose performance is more easily measured. This was not, however, the case in Australian coal mining industry. After examining all the enterprise agreements made during my sample period, I found that the 'productivity bonus', where all the workers receive the same piece rate for each tonne of coal the mine produces, was almost the only incentive contract[8]. Practically, all the jobs were given the *same level*

[8]There are some incidences of individual incentive bonuses. However, the incidences are very rare (only 3% of the total observations).

of incentive, which may have lead to the rejection of the control of incentive theory.

The adaptiveness theory is tested by estimating the effect of coal quality on the adoption of multi-tasking job designs. I use several definitions of coal qualities. First, I use all four individual coal quality (impurity) variables presented in Table 2. Second, I use (Sum_Impurities) which is constructed by summing all the individual coal impurity variables. Summary statistics of coal quality variables are presented in Table 3. Table 6 shows the estimation results of equation 3 and 4. The coefficients for coal quality variables are jointly statistically significant at the 1% significant level for all the models except for (ClassRedu) when (Sum_Impurites) is used as coal quality variable.

The adaptiveness theory indicates that mines with low coal quality (i.e., greater impurity contents) are more likely to adopt multi-tasking. Thus, the partial effects of each coal quality variable on the adoption of multi-tasking are of interest. Table 7 shows the partial effects. Many coefficients show the expected positive sign, i.e., higher impurity contents are associated with greater use of multi-tasking. For example, the logit results show that 1% increase in the sum of coal impurities would increase the likelihood of adopting multi-tasking between production and engineering streams by 5.3%. This points towards supporting the adaptiveness theory. Nonetheless, there are non-trivial number of cases where partial effects show the negative sign (for example, Sulphur for MultTask_Between, Sum_Impurities, Sulphur and Moisture for ClassRedu). Therefore, the evidence is not strong enough to conclusively support the adaptiveness theory .

6.4 An alternative explanation

The tests of the theories suggest that the redundancy elimination is the most plausible source of productivity-enhancing effect of multi-tasking in the Australian coal mining industry. However, one alternative explanation still remains. Even in the absence of a task overlap that enables mines to eliminate redundancy, multi-tasking may improve productivity simply because multi-tasking reduces the likelihood of production disruption (Lazear 1998, p.445). For example, if an engineering worker can also operate a power shovel, the engineering worker can cover the absence of shovel operators. Multi-tasking would increase productivity by reducing the likelihood of production disruption due to workers' absence. This also means that a significant effect of (MultTask_Between) may be due to the reduction in production disruption, and not due to redundancy elimination. Moreover, the magnitude of (ClassRedu) is not small albeit insignificant. The estimated coefficient (0.022) indicates that elimination of all the job classifications (maximum possible elimination is 7) would increase production by 15%. This means that we need more evidence to support the redundancy elimination theory. In order to rule out this alternative explanation, and to strength the support for the redundancy elimination hypothesis, I conduct the following test.

The test is to drop all-contracted mines from our sample. Several mines in my sample have contracted out their production and engineering work to coal contractors. In all-contracted mines, labor turnover may be high because the main purpose of the use of contractors is to make the labor quantity more flexible. Thus, the likelihood of production disruption may be high due to higher frequency of quitting and new hirings. By dropping all-contracted mine, we can partly eliminate the possible productivity-enhancing effect of multi-tasking arising from the reduction in production disruption.

On one hand, if the productivity-enhancing effect is due to redundancy elimination, we expect the following two results. First, the effect of (MultTask_Between) would remain strong due to the presence of task overlap. Second, the effect of (ClassRedu) would decrease because (i) task overlap is absent among the production stream tasks, and (ii) the effect of the reduction in production disruption is eliminated. On the other hand, if the productivity-enhancing effect is not due to redundancy elimination, we expect the effect of both multi-tasking variables to decrease. The last column of Table 5 (a) shows the results. The effect of (MultTask_Between) slightly increases to 0.33. In contrast, the effect of (ClassRedu) drops from 0.022 to 0.014, more than 30% drop in the estimate. This result provides additional support for the redundancy elimination theory.

Thus, my empirical results most strongly support the redundancy elimination theory. Only when overlapping tasks are bundled together, do multi-tasking job designs enhance productivity. I conclude that it is not multi-tasking itself but task contents of multi-tasking that are important. In particular, bundling of overlapping tasks most effectively enhances productivity.

7 Conclusion

After the late 1980s, Australian coal mines vigorously pursued two types of multi-tasking: (I) multi-tasking between production stream and engineering stream tasks and (II) multi-tasking within the production stream. Using an original panel data covering the period 1985 to 2005, I test three existing theories about how multi-tasking job designs affect productivity: *control of incentive* (bundling of tasks with similar performance-measurability makes a performance pay more effective), *redundancy elimination* (bundling of 'overlapping' tasks eliminates duplication of efforts and setup time), and *adaptiveness* (task bundling makes a firm more adaptive to a changing environment). The results strongly support redundancy elimination theory. Only when overlapping tasks are bundled together (type I multi-tasking), does multi-tasking enhance productivity. While type I multi-tasking would increase coal production by 33%, the effect of type II multi-tasking is nonexistent. The control of incentive theory is rejected as bundling tasks with similar performance-measurability (type II multi-tasking) does not enhanced productivity. I do not find conclusive evidence supporting adaptiveness theory, as the association between coal demand uncertainty and the adoption of multi-tasking is weak. It is not multi-tasking itself but specific task contents of multi-tasking that are important. In particular, bundling of overlapping tasks most effectively enhances productivity.

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Table 1: Multi-tasking and other work practice variables

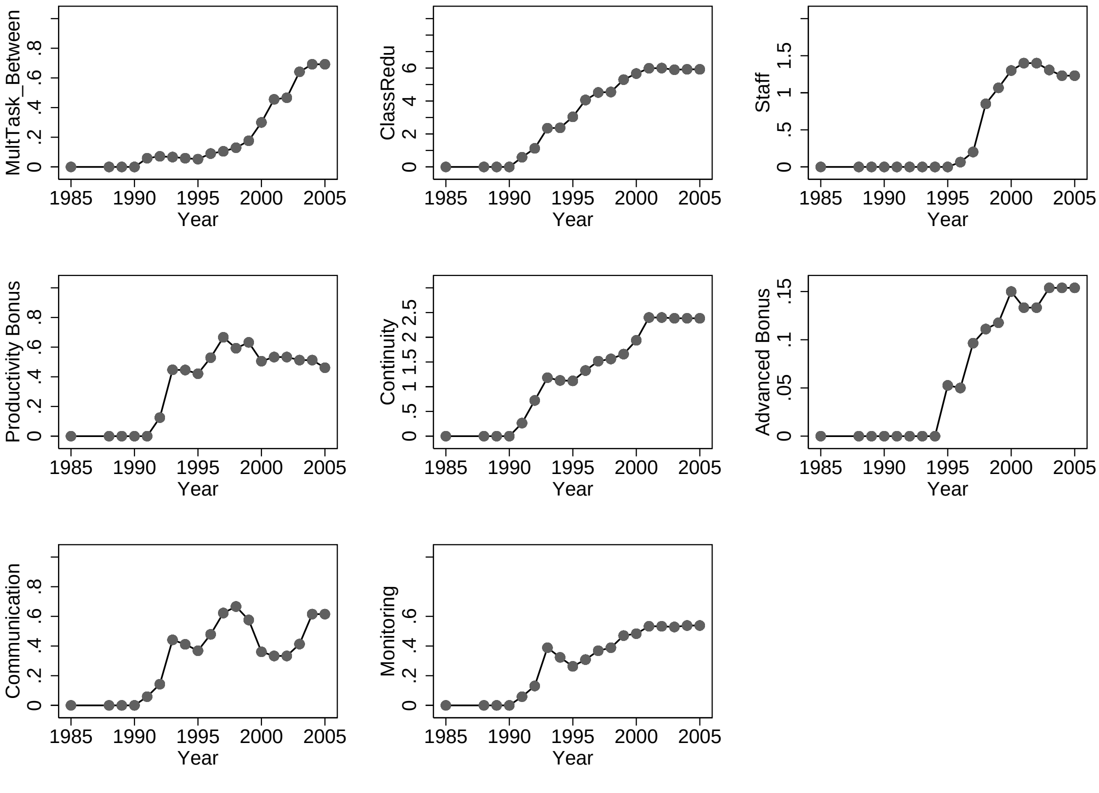
Variables	Definitions
Multi Task Variables	
(ClassRedu)	See Section 3.4
(MultTask_Between)	See Section 3.4
Other Work practice variables	
(Staff)	Sum of the two dummy variables below (Flex_hire)=1 if eliminated hiring restriction(a) (Flex_redundancy)=1 if eliminate redundancy restrictions(b)
(Productivity_bonus)	1 if a mine employs a mine-wide bonus where all workers receive equal piece rate depending on mine level coal production
(Continuity)	Sum of the three dummy variables below (Staggered_break)=1 if the enterprise agreement requires staggered meal breaks to ensure continuity of operations. (Hot_seat_change)=1 if the enterprise agreement requires staggered shift changes to ensure continuity of operations (Shift12)=1 if 12-hour shift is possible.
(Communication)	1 if regularly held labor management meeting exists.
(Monitoring)	1 if individual performance appraisal or team-based monitoring system exists.
(Advanced_bonus)	Sum of two variables below (Indiv_bonus)=1 if individual performance-based bonus exists (Profit share)=1 if profit sharing scheme exists.
(Non_custom_practices)	1 if enterprise agreement eliminates 'Customs and Practices' provision

All the variables are coded from enterprise agreements certified between 1990 and 2005.

(a)P&E Award required that mines should hire previously retrenched worker first when increasing employment (Clause 27).

(b)P&E Award required that mines should first make redundant workers whose tenure is the shortest when reducing employment (Clause 24).

Figure 1:



This figure shows the trend in yearly average of work practice variables over our sample period

Table 2: Dependent, control and instrumental variables

Variables	Definitions
Dependent and control variables	
(Output)	Annual saleable coal production in millions of tonnes
(Employment)	Number of employees during the fiscal year
(Excavator)	Sum of the bucket capacities (in m^3) of draglines, power shovels, front end loaders, and excavators
(Bulldozers)	Sum of engine capacities (in kilowatts) of bulldozers
(Trucks)	Sum of the loading capacities of trucks (in tonnes)
(Thickness)	Average thicknesses of coal seams currently mined
(Oil-Ownership)	Oil Majors' ownership (Shell, Exxon, BP & Esso) in (%/100).
(JPN Ownership)	Japanese ownership in (%/100).
Coal quality variables	
(Ash)	Air dry ash content of coal in %
(Sulphur)	Air dry sulphur content of coal in %
(VolatMatter)	Air dry volatile matter content of coal in %
(Moisture)	Air dry moisture content of coal in %
Dummy(Moisture missing)	Dummy variable indicating moisture information is missing
Additional instrumental variable	
(Distance)	Train distance from the mine to the nearest port in kilometers

There was some missing information for moisture content in the NSW Coal Industry Profiles. Whenever the moisture information is missing, the mine average of non-missing moisture content was imputed. Dummy(Moist missing) indicates whether the value was imputed this way.

Table 3: Summary statistics for selected variables

Variables	Obs	Mean	St Dev	Min	Max
Multi Tasking and other control variables					
MultTask_Between	286	0.21	0.40	0	1
ClassRedu	286	3.47	2.78	0	7
Staff	286	0.52	0.79	0	2
Product_Bonus	286	0.39	0.48	0	1
Continuity	286	1.32	1.10	0	3
Advanced_Bonus	286	0.07	0.25	0	1
Communication	286	0.36	0.47	0	1
Monitoring	286	0.32	0.46	0	1
Output	286	2,944.44	2,416.01	130	13,749.02
Employment	286	280.65	213.02	20	1,160
Bulldozer	286	4,010.61	2,490.33	522	15,918
Trucks	286	3,282.05	2,461.65	180	12,530
JPN ownership	286	0.167	0.282	0	1
Coal quality and instrument					
Ash	286	12.91	5.82	8	35
VolatMatter	286	33.14	2.48	23	38.25
Sulphur	286	0.69	0.21	0	1.65
Moisture	286	3.36	2.02	2	10
Dummy(Moisture missing)	286	0.23	0.42	0	1
Distance	286	109.86	70.17	9	320

a. In Australia, fiscal year starts on July 1st. When a new enterprise agreement has not started at the same time with the fiscal year, the values of the work practice variables are the fraction of the year covered by the enterprise agreement.

b. The values of work practice variables are constant until they are changed by the enterprise agreements that replace the old ones.

Table 4: Overidentification and exogeneity test

Variables	
Instrumented	
MultTask_Between	Yes
ClassRedu	Yes
$N \times R^2$	6.5
ρ_1	0.33
(Sd error)	(0.27)
ρ_2	0.024
(Sd error)	(0.030)

Notation follows Wooldridge (2002, p.119). $N \times R^2$ statistics indicate that overidentifying restrictions are valid. Insignificant estimates for ρ_1 and ρ_2 indicate that multi-tasking variables are not endogenous. (F-statistics for the null hypothesis that both ρ_1 and ρ_2 are jointly equal to zero is 0.86)

Table 5: Production function estimation Results

				Additional Test (a)
	Preferred Model			Eliminate
Variables	Fixed Effect	OLS	2SLS	contractor effet
MultTask_Between	0.31**	0.31***	0.009	0.33*(Pval=.07)
	(0.13)	(0.11)	(0.231)	(0.17)
ClassRedu	0.022	0.055**	-0.002	0.012
	(0.018)	(0.021)	(0.026)	(0.018)
Staff	0.11**	0.13***	0.13***	0.12**
	(0.05)	(0.046)	(0.04)	(0.05)
Product_bonus	0.19***	0.29**	0.10	0.21***
	(0.07)	(0.11)	(0.08)	(0.07)
Continuity	-0.005	-0.14**	0.06	-0.004
	(0.016)	(0.06)	(0.06)	(0.031)
Non_custom_practice	-0.047	-0.1	-0.008	-0.045
	(0.074)	(0.1)	(0.07)	(0.08)
Advanced_bonus	-0.052	-0.098	-0.01	-0.086
	(0.094)	(0.122)	(0.08)	(0.104)
Communication	0.02	-0.015	0.04	-0.014
	(0.049)	(0.063)	(0.05)	(0.054)
Monitoring	-0.048	0.05	-0.02	-0.022
	(0.092)	(0.12)	(0.06)	(0.1)
log(Emploment)	0.73***	0.71***	0.77***	0.70***
	(0.1)	(0.1)	(0.07)	(0.11)
log(Bulldozer)	0.198**	0.14	0.22***	0.29***
	(0.077)	(0.097)	(0.06)	(0.09)
(Japanese Ownership)	1.25**	-0.09	1.00**	1.02*
	(0.58)	(0.52)	(0.50)	(0.58)
$(Japanese Ownership)^2$	-0.93	-0.15	-0.73	-0.69
	(0.63)	(0.55)	(0.48)	(0.61)
R^2(within)	0.86	0.93	0.84	0.85
# observations	286	286	286	253

Inside the parentheses are cluster robust standard errors except for 2SLS. *Significant at 0.1, ** at 0.05, *** at 0.01. Coefficients for some variables are not reported. Entire results are available upon request. (a) Eliminate all-contracted mines from the sample. Based on fixed effect estimation.

Table 6: Effect of coal qualities on the adoption of multi-tasking

	MultTask_Between			ClassRedu		
Models	(Logit)	(OLS)	(Fixed effect)	(OLS)	(OLS)	(Fixed effect)
(Sum_Impurities)	13.6***			-0.25		
	(5.11)			(0.24)		
$(Sum\_Impurities)^2$	-0.10**			0.002		
	(0.04)			(0.002)		
(Ash)		0.068**	0.043		0.50***	0.17
		(0.03)	(0.037)		(0.16)	(0.25)
$(Ash)^2$		-0.0008	0.0001		-0.008***	-0.0018
		(0.0007)	(0.0008)		(0.003)	(0.0043)
(VolatMatter)		-0.63***	0.021		0.80	-2.39*
		(0.12)	(0.17)		(0.63)	(1.2)
$(VolatMatter)^2$		-0.01***	0.0001		-0.01	0.04*
		(0.002)	(0.0029)		(0.01)	(0.021)
(Sulphur)		-0.76**	-1.15		1.52	15.04***
		(0.39)	(0.75)		(2.51)	(3.57)
$(Sulphur)^2$		0.42**	0.57		-2.5*	-8.91***
		(0.21)	(0.38)		(1.4)	(1.71)
(Moisture)		0.15*	0.26**		-0.63	-0.62
		(0.08)	(0.1)		(0.53)	(0.54)
$(Moisture)^2$		-0.013*	-0.021**		0.04	0.038
		(0.007)	(0.009)		(0.05)	(0.049)
R Squared	0.89	0.75	0.75	0.79	0.81	0.85
H_0: Qualities are not joint significant	$\chi^2(2)$ =9.91	F(9,242) =8.60	F(9,22) =5.45	F(2,250) =1.35	F(9,242) =5.72	F(9,20) =5.47

a. All the variables treated as exogenous in the 2SLS estimation of production function (equation 2) are included in the estimation. Thus, fixed effect results are identical to the first stage regressions of the 2SLS procedure.

b. Inside the parentheses are cluster robust Sd Errors. *Significant at 0.1, **Significant at 0.05, ***Significant at 0.01

c. (MultTask_Between) can take fraction (See footnote of Table 3). To discretize the variable, I transformed it as (MultTask_Between)=1 if it is greater than 0.5.

Table 7: Partial effects of coal qualities on the adoption of multi-tasking (based on the results in Table 6)

	MultTask_Between			ClassRedu		
Models	(Logit)	(OLS)	(Fixed effect)	(OLS)	(OLS)	(Fixed effect)
	$\frac{\partial P}{\partial CoalQual}$	$\frac{\partial MultTask}{\partial CoalQual}$	$\frac{\partial MultTask}{\partial CoalQual}$	$\frac{\partial ClassRedu}{\partial CoalQual}$	$\frac{\partial ClassRedu}{\partial CoalQual}$	$\frac{\partial ClassRedu}{\partial CoalQual}$
Sum_Impurities	0.052***			-0.018		
	(9.91)			(1.35)		
Ash		0.045***	0.046***		0.29***	0.12
		(6.67)	(5.24)		(6.00)	(0.78)
VolatMatter		0.13***	0.23**		0.02	0.26
		(27.4)	(4.01)		(0.42)	(2.00)
Sulphur		-0.17	-0.36		-1.87***	2.74***
		(1.97)	(1.17)		(13.78)	(20.8)
Moisture		0.063	0.12*		-6.00*	-0.36*
		(1.92)	(3.00)		(2.84)	(2.82)

a. Inside the parentheses are the test statistics for the null hypothesis that the coefficients for the coal quality variable and its square are jointly equal to zero. They are F statistics except for Logit model where chi square statistic is used.

b. *Significant at 0.1, **Significant at 0.05, ***Significant at 0.01

c. Partial effects are computed at the sample average of each variable except for logit model. For logit, sample average of partial effects is shown.

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