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Assessing determinants of industrial waste reuse: The case of coal ash in the United States

Joo Young Park*

Yale School of Forestry and Environmental Studies, 195 Prospect Street, New Haven, CT 06511, United States

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ABSTRACT

Devising effective strategies to facilitate waste reuse depends on the solid understanding of reuse behaviors. However, previous studies of reuse behavior have been limited in scope, focusing mostly on household recycling behaviors or very limited types of industrial wastes. To gain a better understanding of the business reuse behaviors, this study examined the impact of various factors in technical, economic, regulatory, and behavioral categories in the case of coal ash generated in the United States. The results of fixed effect models for fly ash and bottom ash particularly showed the significance role of the behavioral factor. In both models, a proxy variable, which represents knowledge sharing among the power plants or the utility's decision-making, turned out to be statistically significant and had the largest coefficient estimates among a group of variables. This finding may imply that the characteristics of waste reuse behavior are determined more by business decision-making behaviors than by market or institutional factors. However, the role of the behavioral variable was stronger in the bottom ash models than in the fly ash models. While the reuse of bottom ash was determined primarily by the behavioral variable, fly ash reuse was determined by more diverse factors including economic and regulatory variables. This could be explained by material characteristics in relation to competing resources and the nature of reuse applications.

1. Introduction

Comprehensive statistics for industrial waste are lacking, but a few statistics including the OECD Environmental Data Compendium, allow us to conjecture the enormous amount of industrial waste (Chertow and Park, 2011). In the United States, the crude estimate made in the mid-1980s for non-hazardous industrial waste was approximately 11 billion metric tons (U.S. Congress, 1992), compared to 0.2 million metric tons of municipal solid waste generated in the time period. Despite its massive quantity, industrial waste has received less attention than household waste in studies that examined reuse behaviors. While a significant volume of literature has studied household recycling behaviors (Barr, 2007; Cheung et al., 1999; Chu and Chiu, 2003; Guerin et al., 2001; Oskamp et al., 1991), only a limited number of studies have examined the reuse behavior for industrial waste, particularly construction waste (Al-Sari et al., 2012; Begum et al., 2009; Manowong, 2012; Teo and Loosemore, 2001). Within the management literature, waste reuse has often been considered one component of corporate environmental management options (Liu et al., 2010; Papagiannakis and Lioukas, 2012; Zhang et al., 2008) but has not received sole attention for detailed analyses and modeling.

To understand how businesses reuse their waste, this article examines factors that determine reuse and quantifies the extent of their influence. The determining factors are classified into technical, economic, regulatory, and behavioral categories, as reuse occurs only with the right mix of these types of factors (BCSD-GM, 1997; Gibbs, 2003; Mirata, 2004). The reuse needs to be technically feasible and economically sound. To implement reuse that is technically feasible and economically sound, industrial actors need to have the right resources in the informational, organizational, and/or social dimensions, which are categorized here as behavioral factors. It also requires supportive regulatory instruments, which otherwise can impede reuse (Frosch, 1994). Understanding the role of each type of factor would help to devise effective strategies to promote the reuse of industrial waste.

Among these factors, this study draws particular attention to the role of behavioral factors in the reuse of industrial waste. Behavioral factors have received increasing attention in the

* Tel.: +1 475 201 8237.
E-mail addresses: jooyoung.park.jp637@gmail.com, jooyoung.park.jp637@yale.edu

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literature of industrial symbiosis, which addresses the form of waste reuse that occurs through direct interaction and cooperation among industrial actors rather than through secondary markets. In explaining why certain reuse did not happen even in the presence of economic gains, many studies recognized the role of behavioral factors such as communication, trust, and attitudes toward cooperation. These factors allow businesses to share proprietary information about waste and to cooperate despite uncertainty and risk involved in the transaction (Boons and Howard-Grenville, 2009; Cohen-Rosenthal, 2000; Gibbs, 2003; Gibbs and Deutz, 2005; Hewes and Lyons, 2008; Wolf et al., 2005). Because of the important role of communication along social ties, Sterr and Ott (2004) argued that waste reuse is difficult to occur beyond a regional scale. Ashton (2008) found that waste reuse transactions showed higher correlations with trust than product transactions along the supply chain. For these reasons, inter-firm waste reuse has been understood more as a cooperation problem rather than a simple economic decision (Baas, 2008; Batten, 2009; Boons and Berends, 2001; Boons and Baas, 1997).

Successful reuse may rely more on behavioral factors because of the uncertainty involved. Contrary to products that are extracted and processed according to demand, waste materials are unintentionally generated decoupled from demand in terms of timing and quantity (Tibben-Lembke and Rogers, 2002; Toffel, 2004). Such decoupling between demand and supply makes the price of a waste material volatile, causing uncertainty, which in turn makes price more volatile, especially linked to other market failures (Stromberg, 2004). Furthermore, waste tends to be generated in distributed origins and in varying forms and quality, increasing costs such as for collection, processing, monitoring, and transportation. Instead of having independent markets, waste materials are used as substitutes for products, which make their reuse a lower priority. To reduce such uncertainty arising from limited capability in knowledge and complexity in waste reuse, intentionally rational actors tend to resort to social devices (Beckert, 1996; Dequech, 2003).

For empirical investigation, this study takes coal ash as a test case among various types of industrial waste. In the United States, coal ash is one of the largest industrial waste streams, with its annual generation reaching up to 80–90 million metric tons (ACAA, 2000–2011). It collectively refers to fly ash and bottom ash, both generated from coal-fired electricity production process. Fly ash is a fine and powdery fraction captured from a flue gas by particulate control equipment and bottom ash is a coarser and heavier fraction collected at the bottom of the furnace. Fly ash is known for its value in concrete applications, which can typically replace 15–35% of cement in concrete, and it is also a popular ingredient for fills, embankments, and soil stabilization. Bottom ash is mostly used for aggregate, offsetting the use of sand and gravel in structural fills, road base, and pavement. In the United States, approximately 40% of coal ash has been reused each year (ACAA, 2000–2011), compared to 80–90% in Japan and the EU (European Coal Combustion Products Association, 2008; JCOAL, 2009).

Using 10 years of data between 1996 and 2005, this study conducted regression analyses to measure the impact of selected variables in technical, economic, regulatory, and behavioral aspects. The article begins with reviewing factors that can influence the reuse of waste in general, and more specifically, the reuse of coal ash. Based on these investigations and data availability, a group of variables were selected for analysis. The article then presents the structure of the regression model, followed by the estimation results and discussions. In the discussion session, the results of the fly ash models and bottom ash models are compared to shed light on the understanding of reuse behaviors for different types of waste materials.

2. Materials and methods

2.1. Dependent variables and data

To represent the reuse behaviors of a business, two dependent variables were first chosen: a binary variable indicating participation in reuse, and a continuous variable representing the reuse rate of coal ash. The former dependent variable took the value of zero when a power plant did not reuse coal ash or one when the plant reused coal ash regardless of the reuse amount or reuse rate. This would address the question of which factors determine the business decision whether to participate in reuse. The latter dependent variable, the reuse rate, was used to examine the influence of factors on the extent of reuse. It was calculated by dividing coal ash sold by its total generation. It was chosen over the quantity of coal ash reused because the reuse quantity would be determined largely by the amount of coal burned and the average ash content and therefore would shadow the effect of other variables. Both dependent variables reflect the view of waste generators (i.e., coal-fired power plants in this study), which face a decision about whether to dispose of or sell ash for further uses and how much. It was assumed that all coal ash sold was reused because no information was available regarding the end-user, or for what applications the ash was sold.

Data for these two dependent variables were taken from the Energy Information Administration (EIA) form 767, "Steam-Electric Plant Operation and Design Report," which documents extensive information for all steam-electric power plants larger than 10 MW. In addition to information about net electricity generation, fuel consumption, boiler, generator, and emission control equipment, EIA-767 contains information about by-product disposition: the amount of coal ash disposed of in a landfill/pond, stored on-site, sent to offsite, or sold. These data were available at the plant or subplant level. To control the effect of fuel type on the quality of coal ash, only coal ash generated from fuels with more than 80% bituminous, sub-bituminous, anthracite, or lignite coal were included in the analysis. Fuel information was taken from EIA form 906.

Fig. 1 shows some examples of the reuse rate of fly ash for selected power plants over the observed time period to understand different patterns of reuse behaviors. During the time period between 1996 and 2005, some power plants never sold fly ash, whereas some plants sold all of the fly ash they generated. The number of plants that sold 0% or 100% of fly ash over the observed years constituted 27.4% and 1.6% of the total 449 plants, respectively. For some power plants, reuse rates remained relatively constant, increased or decreased continuously, or fluctuated. As shown in the case for plant number 991, high reuse rates in certain years could be followed by no reuse in the following year. For more details about the data, the changes in the reuse rate of fly ash and bottom ash are presented at the state level, which can be found in Appendix.

2.2. Independent variables and data

2.2.1. Technical variables

Technical variables refer to factors that directly or indirectly influence the quantity and/or quality of waste materials and thus, their reuse. Technologies that collect, separate, or process waste materials have a direct influence on waste materials so as to make them satisfy certain specifications for reuse. However, even though not intentional, some changes made in a technological portfolio in a firm, whether it is for enhancing production efficiency or for being compliant with regulations, may also influence the quantity and/or quality of waste.

In the case of coal ash, its quality is influenced by coal type, combustion process, air pollution control technology, and the management practice. For example, the use of low-NO_x burners or