Causality Between Main Product and Byproduct Prices of Metals Used for Thin-Film PV Cells

Haeyeon Kim

Department of Energy Systems Engineering

Seoul National University

599 Gwanak-ro, Gwanak-gu

Seoul, 151-744, Republic of Korea

Phone: +82-2-880-8284, Fax: +82-2-882-2109

E-mail: yeon0312@snu.ac.kr

Eunnyeong Heo

Department of Energy Systems Engineering

Seoul National University

599 Gwanak-ro, Gwanak-gu

Seoul, 151-744, Republic of Korea

Phone: +82-2-880-8284, Fax: +82-2-882-2109

E-mail: heoe@snu.ac.kr

1. Introduction

Solar power is one of the most promising renewable energy sources. The source of solar power is almost limitless and does not produce significant pollution. Photovoltaic (PV) cells are a type of solar power device that convert sunlight into electricity. As concerns relating to renewable energy grow, the potential of PV cells as an important source of electricity increases. Although thin-film PV cells, also known as second-generation PV cells, are in the growth phase, their market has not yet matured, presenting significant opportunities for Asian countries leading in advanced technologies.

Thin-film cells need specific metals according to their types. For example, as its name indicates, a CIGS cell needs copper, indium, gallium, and selenium to make up a complete cell. Meanwhile, other types of cells require cadmium, tellurium, and germanium (Donald, 2010). Even though only small quantities of these metals are included in a cell, they play a critical role. With the exception of copper, the metals mentioned above are produced as byproducts.

Certain metals are commonly produced together. This process is called joint production and is a typical feature of the mining industry. The results of joint production are divided into three groups according to their economic importance. The main product or principal product is the product that accounts for a significant portion of the revenue. Accordingly, it is a major factor in a mine’s decision-making. Two or more metals influencing decision-making are called coproducts. On the other hand, the byproduct is an output that does not have significant influence on the entire mine. Its supply depends on that of the main product, that is, the amount of the byproduct is limited by the output of the main product. As a result, the supply function of a byproduct includes the price of the supply the main product (Tilton, 1985). Furthermore, prices of related metals may also affect those of others (Campbell, 1985).

The main objective of this study is to determine whether there is relationship between the prices of byproduct metals used in making PV cells and those of related metals. Many existing studies analyzed the causality among metal prices. Most of the previous studies examined either precious metals such as gold, silver (Escribano and Granger, 1998; Ciner, 2001; Sari et al., 2010), or base metals (Macdonald and Taylor, 1988; Jones and Uri, 1990). Meanwhile, empirical studies investigating metal prices based on product types are rather scarce. In this study, we analyzed the price relationships of byproducts and main products using the Granger causality test. Based on the data availability, the targeted metals in this study are those used to make thin-film PV cells, specifically, cadmium (Cd), germanium (Ge), indium (In), and selenium (Se). Cadmium, germanium, and indium are byproducts of zinc while selenium is a byproduct of copper.

2. Method

Applying ordinary least squares (OLS) regression in analyzing time-series data would likely cause spurious regression. Spurious regression is that in which seemingly significant correlation is found among unrelated variables. To prevent this problem, the stationarity of the data should be checked in advance. This study employs the augmented Dickey-Fuller (ADF) test (Said and Dickey, 1984), Phillips-Perron (PP) test (Phillips and Perron, 1988), and Kwiatkowsk-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992) to check for stationarity. Unlike the ADF and PP tests, the KPSS test sets the stationarity of time-series as a null hypothesis. Accordingly, conducting tests for which null hypotheses are exclusive may have higher reliability. Once a time-series is found to be non-stationary, OLS should not be applied.

Even though individual time-series are non-stationary, their linear combinations may be stationary, in which case the time series are said to be cointegrated. Cointegration represents the long-run equilibrium of the variables. To identify the existence of cointegration, the Johansen cointegration test (Johansen, 1995) is used. This test employs a test statistic called trace statistic. If cointegration of the variables exists, there is an error correction representation (Engle and Granger, 1987), the expression of which is called the vector error correction model (VECM). The basic form of the VECM can be written as:

$$\Delta y_t = \alpha + \gamma(y_{t-1} - \beta x_{t-1}) + \sum \delta_i \Delta x_{t-i} + \sum \theta_i \Delta y_{t-i} + \varepsilon_t \quad (1)$$

where x and y denote the prices of the byproduct and main product, respectively. The coefficient γ implies how fast x and y revert to long-run equilibrium. In the case where variables are not cointegrated, the vector autoregression (VAR) model using differenced variables of non-stationary series is recommended. A basic VAR model is composed of two variables as shown below. In this model, distinguishing endogenous from exogenous variables is not necessary:

$$y_t = \alpha + \sum \delta_i x_{t-i} + \sum \theta_i y_{t-i} + \varepsilon_t \quad (2)$$

After constructing the model according to the result of the cointegration test, we conducted the Granger causality test to determine the causality between the prices of the metals (Granger, 1969). This test enables us to verify the statistical causality of the variables.

3. Empirical results

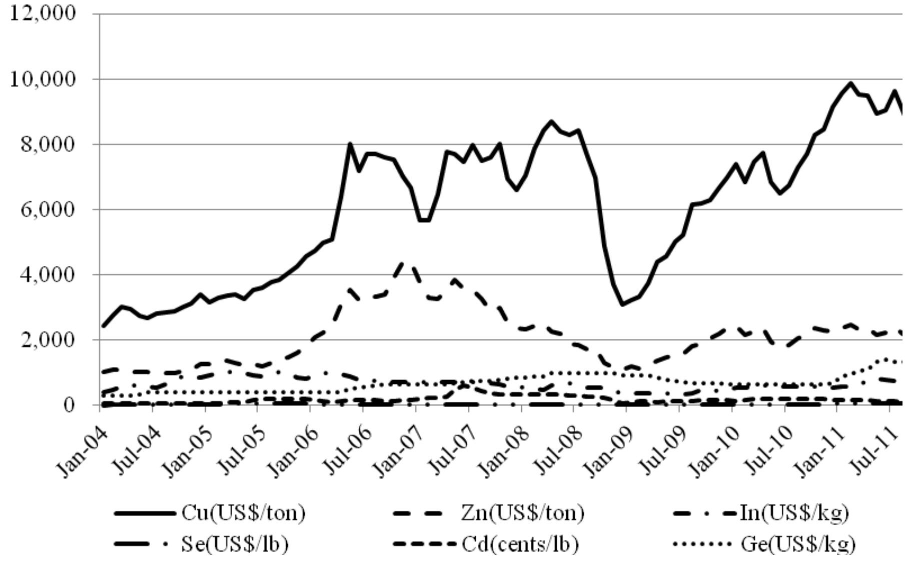
3.1 Data description

Table 1 presents the basic statistics of the metal prices used in this study. The data cover the period from January 2004 to November 2011. The units and sources of the prices differ since each metal is traded differently. The prices of copper (Cu) and zinc (Zn) are based on LME cash price while those for the other metals were derived from the Metal Bulletin free market price. Figure 1 illustrates the prices of the six metals for the years 2004 to 2011. As demonstrated by the figure, the prices of the metals fluctuated during the period.

Table 1. Basic statistics of metals prices

Variable	Unit	Mean	Std. Dev.	Min	Max
Cd	cents/lb	181.66	107.92	50.00	611.25
Ge	US$/kg	726.63	465.78	315.00	4387.50
In	US$/kg	666.65	184.75	340.00	1035.00
Se	US$/lb	34.48	13.76	9.00	67.60
Cu	US$/ton	6091.58	2174.88	2423.57	9867.60
Zn	US$/ton	2107.53	858.93	975.18	4402.86

Figure 1. Metal prices, 2004-2011



Tables 2 and 3 present the results of the unit root test. The level series of the prices have unit roots except for the price of germanium, which was found to be stationary. For the non-stationary prices of other metals, we performed an additional unit root test using the first-differenced form. The ADF and PP statistics of the first-differenced variables were significant at the 1% level and the null hypothesis that the series are non-stationary was rejected. The first-differenced prices of cadmium, copper, and zinc had insignificant KPSS statistics, while those of indium and selenium were significant at the 10% level. Since two of the three statistics for indium and selenium indicate that the variables are stationary, it is concluded that all the prices in their first-differenced form are stationary.

Table 2. Unit root test in level series

Variables	ADF	PP	KPSS
Cd	-1.780	-2.157	0.297***
Ge	-5.234	-5.174	0.113
In	-1.786	-1.997	0.259***
Se	-0.919	-1.567	0.246***
Cu	-1.729	-1.967	0.266***
Zn	-1.516	-1.717	0.416***

*, **, and *** indicate 10%, 5%, and 1% significance levels, respectively.

Table 3. Unit root test in 1st differenced series

Variables	ADF	PP	KPSS
Cd	-5.566***	-5.402***	0.040
Ge	-	-	-
In	-6.080***	-5.821***	0.164*
Se	-4.751***	-4.778***	0.122*
Cu	-6.656***	-6.662***	0.059
Zn	-6.714***	-6.627***	0.107

*, **, and *** indicate 10%, 5%, and 1% significance levels, respectively.

Based on the results of the unit root test, we conducted the Johansen's test to determine any cointegration among the variables. The lag length was selected by the Schwarz Bayesian information criterion (SBIC). In all three cases, the trace statistics are smaller than the 5% critical value. Therefore, we are unable to reject the null hypothesis that the rank is zero, which implies that the variables are not cointegrated. Since there is no cointegration, we construct the VAR model using the first differenced prices and test for Granger causality. Since the price of germanium is stationary in its original form, the level series were used in the VAR model.

Table 4. Results of the Johansen test

y	x	Rank	Optimal lag	Trace statistic
Cd	Zn	r = 0	3 (23.342)	15.284
In	Zn	r = 0	2 (24.289)	11.386
Se	Cu	r = 0	2 (20.503)	9.064

Cu	Zn	r = 0	2 (28.356)	10.700

Note: The 5% critical value for the Johansen test is 15.41.

3.2 Empirical results

Table 5 presents the results of the Granger causality test. For cadmium-zinc and selenium-copper, the null hypothesis that the change in the price of a byproduct does not Granger-cause the change in the prices of a main product was rejected at the 5% significance level. For germanium, the null hypothesis that the price of a byproduct does not Granger-cause the change in the price of a main product was rejected at the 10% significance level. For indium-zinc, the null hypothesis that the change in the price of a main product does not Granger-cause change in the price of a byproduct was not rejected. In all four cases, the null hypothesis that the change in the price of a byproduct (or the price itself for germanium) does not Granger-cause change in the price of a main product was not rejected. To determine the overall relationship of the metals covered in this study, we checked for cointegration among the main product metals, that is, copper and zinc. In doing so, the null hypothesis was not rejected. Figure 2 briefly illustrates the results.

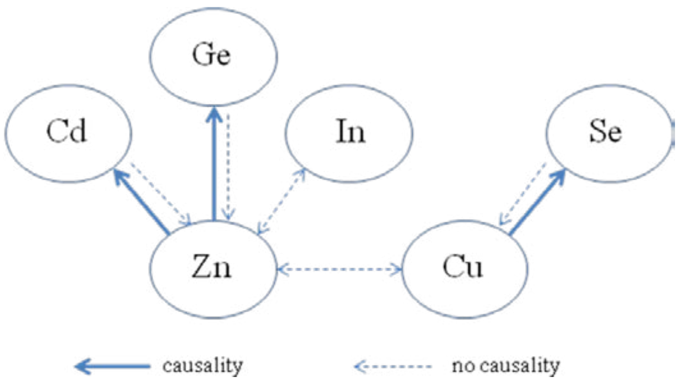
Table 5. Results of the Johansen test

Null hypothesis	**Optimal lag**	χ^2
Change in price of zinc does not Granger-cause change in price of cadmium.	2 (23.340)	8.519** (0.014)
Change in price of cadmium does not Granger-cause change in price of zinc.		0.107 (0.948)
Change in price of zinc does not Granger-cause in price of germanium.	1 (28.511)	3.126* (0.077)
Germanium price does not Granger-cause change in price of zinc.		0.244 (0.621)
Change in price of zinc does not Granger-cause change in price of indium.	2 (24.205)	0.561 (0.755)
Change in price of indium does not Granger-cause change in price of zinc.		0.988 (0.610)

Change in price of copper does not Granger-cause change in price of selenium.	1 (20.414)	4.571** (0.033)
Change in price of selenium does not Granger-cause change in price of copper.		0.004 (0.952)
Change in price of zinc does not Granger-cause change in price of copper.	2 (28.356)	4.124 (0.127)
Change in price of copper does not Granger-cause change in price of zinc.		0.270 (0.874)

1) *, **, *** indicate 10%, 5%, 1% significance level, respectively.

Figure 2. Granger causality of metal prices



4. Conclusions

The results of the unit root tests indicate that the prices of metals are non-stationary in level form and stationary in their first-differenced form, except for germanium. In constructing the cointegration equations for the three cases (cadmium-zinc, indium-zinc, and selenium-copper) and conducting the Johansen test, this study did not find any cointegration in any of the cases. Therefore, we constructed the VAR model with stationary data, that is, level series for germanium and first-differenced series for other metals. Among the four byproduct metals, the prices of cadmium, germanium, and selenium are Granger-caused by the main product's price. Specifically, the changes in the prices of cadmium and selenium are Granger-caused by those of the main product. In case of germanium, the change in the price of the main product (zinc) Granger-caused that of the byproduct (germanium). To determine the overall relationship of the prices of the metals, we checked for cointegration between the copper and zinc prices. However, the result of the test revealed no cointegration. Granger causality represents statistical causality rather than logical causality of the variables, which implies that cases with Granger causality may be used to determine the prices of the byproduct metals. Even though the byproduct metals covered in this study are produced in small quantities, their role in industrial application is critical. Most existing studies that investigated the prices of metals focused on precious metals or base metals. The results of this study may provide a starting point for the further examination of the prices of other industrial metals. Future studies should consider more detailed features of each of the metals covered.

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