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Econometric modeling of recycled copper supply

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ABSTRACT

The supply of recycled material depends on historic consumption, i.e. what constitutes scrap available today originates from previously made products. Analytical tools, such as materials flow analysis, use this observation to estimate scrap metal flows. The supply of recycled metal also depends on changing economic conditions, e.g. metal consumption rates correlate with changes in gross domestic product. We use an autoregressive distributed lag approach to model the supply of recycled copper as a complementary approach to material flow analysis. We find that both industrial activity and world GDP correlate with total scrap supply, with limited dependence on copper price. We also develop independent models for direct remelt (higher quality) and refined (lower quality) scrap. A 1% increase in industrial production leads to a 2.1% increase in higher quality scrap quantity, while a similar increase in world GDP leads to a 1.4% increase in lower quality scrap. Based on this model dependence, we suggest that a recycling policy aimed at increasing recycling through the use of subsidies, taxes or price incentives should be directed towards the low-end segment of the scrap market and there it may still only have limited impact.

1. Introduction

Approximately 33% of the copper consumed worldwide is derived from secondary sources, i.e. it has either been part of a product or it has been collected as waste from a manufacturing process (Gloser et al., 2013). While the fraction of secondary versus primary (derived from ore) has stayed between 30 and 40% over the past 40 years; in absolute terms the use of copper from secondary sources has tripled over the same period (ICSG, 2013). The collection of copper scrap is desirable from an environmental perspective for two primary reasons (Gomez et al., 2007; Northey et al., 2014; Reck and Graedel, 2012). First, copper is relatively scarce compared to other industrial metals: by one metric, the static depletion index, the time to exhaust current reserves is only about 40 years, while ore grade for copper, is 0.2–5 wt% (recent values less than 0.45 wt%) (Ruth, 1995). Although not accounting for increased demand or improved efficiency from extraction technology, this metric is an order of magnitude lower than that of aluminum and iron (Alonso et al., 2007). Second, as is typical for metals, copper production from secondary sources requires less energy than that from primary sources: for some grades of copper secondary production reduces energy needs by 85% compared to primary production (Rankin, 2011). There is economic incentive as well: multiplying the year average price of \$3.4/lb by estimates for annual scrap flows (Gloser et al., 2013), the nominal value of the copper in global waste streams in 2010 was \$81 billion.

As a result of these drivers, much effort has gone into understanding the various technical (Gaustad et al., 2010; Olivetti et al., 2011), economic (Achillas et al., 2013) and life cycle (Rubin et al., 2014) aspects of improving recycling. To this end, materials flow analysis (MFA) provides a diagnostic modeling tool for analyzing materials systems (Liu and Muller, 2013; Muller et al., 2014). The results of an MFA covering end of life fate of a material describe waste generation flows and identify where dissipative losses occur (Lifset et al., 2012); furthermore, results may be tracked over time and compared across geographic regions, thereby identifying high leverage opportunities for increased recovery (Wubbeke and Heroth, 2014). MFA models can also provide estimates of metrics that are otherwise not reported directly by recyclers, such as recycling and collection rates for different end-use sectors (Chen, 2013). Information of this sort can be used to inform industry and government strategy aimed at increasing these rates (Gsodam et al., 2014; Habuer et al., 2014; Wang et al., 2014). In an MFA model the material recovered in a year is typically estimated based on historical materials consumption, estimated product lifetimes, and collection rates (Bertram et al., 2002; Cullen and Allwood, 2013). These models therefore, by design, assume that past patterns of behavior are consistent with those into the future and do not directly incorporate the effect of changing economic conditions. As incentives to use, discard, collect and recycle copper and copper containing

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products depend on the immediate economic situation for particular agents in the system, a solely MFA-based approach may lead to an incomplete description of scrap supply (McMillan et al., 2010). Complementary to MFAs, econometric analysis is used to model scrap volumes based on incorporating an array of independent variables describing various facets of the economy (Angus et al., 2012). Many of these variables, such as indices of industrial production (IP), are routinely forecasted with reasonable fidelity. The relative ease with which data can be obtained make econometric modeling an attractive route for projecting future scrap flows. In this paper, we use ordinary least squares to model the supply of recycled copper. Copper was chosen because of data availability and its economic importance, i.e., a combination of significant amounts of global production and relatively high price.

The economic analysis of metals markets has often been studied from a financial (Baffes and Savescu, 2014) and a resource economics (Slade, 1982; Solow, 1974) point of view. The modeling of metals supply and demand has been developed for the primary industry (Alonso et al., 2012; Wagenhals, 1984). A few studies have also focused on the supply of secondary metal including copper. For example, economic models have shown that secondary production correlates with price (Blomberg and Soderholm, 2009; Gleich et al., 2013), production inputs (Slade, 1980) and the available stock of copper scrap not recycled in earlier years (Gomez et al., 2007). Results of this sort are valuable when designing policy strategy intended to influence materials recovery, e.g. fiscal subsidies directed towards material recovery are effective only if scrap flow responds to changes in price (Finnveden et al., 2013; Mansikkasalo et al., 2014; Soderholm, 2011; Soderholm and Tilton, 2012).

The above studies focus on the refinery sector of the recycling industry, which, in the case of copper, includes only 42% of recycled metal globally, i.e., scrap that can be directly melted without being refined is not counted (ICSG, 2013). The important distinction between the two types of scrap is not necessarily the source (e.g. old versus new scrap), but rather the quality (e.g. end-of-life power cable versus waste electrical and electronic equipment) (Flores et al., 2014). The focus of previous work on a subset of the recycling industry, i.e. the refinery sector, limits its applicability to relatively lower grade scrap and the products that make up such scrap. They are less useful for improving direct melt scrap recycling because this part of the market consists of different products and different waste collection streams. A large part of this stream is waste from semi-finished goods production. Through econometric modeling of scrap volumes with annual sampling frequency, both globally and regionally, we investigate what might drive availability of different qualities of scrap. We discuss our findings in light of environmental policy strategy towards increasing scrap availability. Specifically, we show whether price and what other forms of economic activity affect different parts of the copper waste stream.

2. Data and methods

We first study the world consumption of copper scrap with *annual* sampling frequency between 1972 and 2012 from the International Copper Study Group (ICSG) database (ICSG, 2013). This dataset is partitioned into scrap that is first refined before use (refined scrap) and scrap that can be directly melted at the time of use (direct melt scrap). The latter category comprises secondary copper that requires minimal processing in order to be used in a new product, i.e. high purity and/or knowledge of chemical composition.

The dependent variables are the quantities of copper produced from secondary sources (annual). In the literature, these quantities are sometimes referred to as supply, consumption or flow (Blomberg and Soderholm, 2009; Gloser et al., 2013; Gomez et al., 2007). Henceforth, we will refer to them as copper supply. The independent variables, i.e. the potential drivers for secondary copper supply are captured by indices of industrial activity, prices, and monetary conditions. They were chosen based on a survey of econometric literature pertinent to metals markets and aim to be comprehensive in their coverage of activities that may influence the supply and demand of copper more generally (Azadeh et al., 2013; Elshkaki et al., 2005; Finnveden, Ekvall, 2013, Reck and Graedel, 2012). The choice of independent variables was also based on our interest in reflecting scrap generation rather than scrap consumption. For example, while China consumes large amounts of copper, most postconsumer scrap is still generated in the major advanced economies (represented by the G7 countries). The price variable is the real price of refined primary copper from the London Metal Exchange (LME). Based on copper-content, scrap is traded at a discount relative to the primary price, but the correlation between primary and secondary prices is very strong (Xiarchos and Fletcher, 2009). The complete list of variables considered is available in Table S1 in the supporting information.

Prior to performing the regression analysis, we logarithmically transformed all variables that reflect quantity, price and value, in order to stabilize variable variance. Price, futures and world GDP are deflated by world real GDP deflator. In addition, it is common practice in econometrics to consider de-trending data. A linear trend in both the predictors and the response may cause the model to have a high goodness of fit. This leads to a problem called spurious regression, and the model developed this way will not accurately reflect the causal relationships between the variables. Therefore, in order to remove the deterministic (linear) trend of variables, all the variables are regressed against time, which is the year variable in our case. This is equivalent to adding (or forcing) ‘year’ as an independent variable (Hamilton, 1994).

We note that de-trending of a time series can also be performed by “differencing” if there is a stochastic trend, and results from the Augmented Dickey-Fuller (ADF) unit root test show that all variables are non-stationary in levels and stationary in first differences except for interest rates. The ADF test speaks to data stationarity, i.e., whether the statistical properties of the time series are constant over time; further detail on this test can be found in the supplementary information. However, here we focus on de-trending the deterministic trend (Hamilton, 1994). By adding the time term in the models we are able to capture unobserved effects that might drive copper supply to increase exponentially, such as technology improvement, population growth, etc. Interested readers can refer to Fig. S1 in the supporting information, where we find that the model which starts with differencing does not fit the actual data as well as the model which starts with linear de-trending.

The relationships between dependent and independent variables were modeled using autoregressive distributed lag (ARDL) model. The modeling method consisted of five basic steps designed to understand which type of independent variable correlates with scrap volumes over time. First, we grouped the hypothesized explanatory variables by identifying those that had strong correlation ($\rho^2 > 0.5$) to end up with candidates from each hypothesis of what may drive scrap availability (this is a modeling assertion to consider possible influence from the hypothesized categories). Once we obtained these groups, we used the correlation coefficient between independent variables and explanatory variables within each group to decide which variable from each group to move into the next step. In addition to individual variables, we also included all possible combinations of first-order interaction terms. In this way, we screened for the most influencial variable within a category.

Next, in order to further reduce the number of explanatory variables used, we use forward stepwise regression for variable selection. The variable to include in each step is based on Bayesian