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Valuing environmental impacts of mercury emissions from gold mining: Dollar per troy ounce estimates for twelve open-pit, small-scale, and artisanal mining sites

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ABSTRACT

Mercury is a toxic pollutant that distributes globally once emitted into the air. Mercury emission is the primary environmental impact of small-scale and artisanal gold mining, which are responsible for nearly half of anthropogenic mercury emissions each year. Considering that small-scale, artisanal, and formal gold mining are linked by the global gold price, this analysis evaluates the question - In dollar terms, what is the difference in mercury emission impact, per ounce of gold production, from these three forms of mining? To answer this question, a calibrated benefit transfer approach is employed to apply environmental valuation literature estimates (of mercury's impact on global earnings) to twelve gold mining sites around the world. The results indicate a mean impact range of < \$1–\$5 for two formally operated open-pit mines in Nevada, \$200–\$600 for small-scale and artisanal sites that concentrate gold ore prior to mercury amalgamation, and \$500–\$3200 for small-scale and artisanal sites that amalgamate all of the ore. Given the vast disparity between impact per ounce estimates, even small leakages in gold production from formal to informal operations could increase the net environmental impact of global gold production. Future research ought to estimate this leakage rate by modeling small-scale and artisanal miners' price elasticity of supply.

1. Introduction

Developed countries seek ever higher levels of environmental quality for their own populations and, even, for the globe as a whole. As the burdens of environmental regulation in developed countries increase, industrial production - and its pollution - are shifting into less developed countries with lower environmental standards. This effect, known in the economics literature as leakage, has been well documented (Paltsev, 2001; Babiker, 2005; Balistreri and Worley, 2009). For anthropogenic green house gas emissions, Babiker (2005) indicates that leakage rates can be as high as 130% – which would mean that environmental regulations in developed countries result in a net *increase* of the external cost from the pollutant they seek to abate. This suggests that the difference between emission rates is an important factor in determining the net outcome of environmental regulation. The literature surrounding leakage is mute regarding mining even though both subjects share defining characteristics such as internationally mobile capital, globally significant pollution flows, and emission rate differentials between developed and developing countries.[1]

For the purposes of this analysis, the mining industry is exemplified by gold production and is decomposed into three contexts: publicly-traded trans-national mining corporations (TNMCs), small-scale mining operations, and artisanal mining operations. Although TNMCs are radically different from small-scale and artisanal mining, these three forms of gold production are all linked by the international gold trade and the global price of gold. TNMCs are the major mining companies that operate projects around the world. Their shares are traded on global exchanges and their activities are scrutinized by civil society. Today, TNMCs strive to limit the social and environmental impact of their operations in order to maintain their reputation, their ability to negotiate future acquisitions, and ultimately, their share-price (Davis and Franks, 2011). As a result, TNMCs have strong financial incentives to operate at the highest industry standards, which reflect environmental regulations in the most developed countries (Davis and Franks, 2011).

Small-scale mining, on the other hand, generally consists of mining operations in developing countries that rely on a combination of manpower and machinery to achieve a relatively small capacity of gold ore production (McMahon, 1999; Veiga et al., 2004). Small-scale

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[1] Balistreri and Worley (2009) tangentially frame mercury leakage as new primary mercury mining. However, the main focus of the study is a comparison between a US mercury export ban and a US mercury purchase program.

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mining operations are small, remote, and difficult to regulate. Environmental damage is often significant despite smaller capacity (McMahon, 1999; Rodrigues-Filho et al., 2004; Veiga et al., 2004). Similarly, artisanal mining consists of rudimentary gold mining as a subsistence activity. Artisanal mining is generally characterized by limited land tenure, social disruptions, environmental degradation, and significant endangerment to the health of miners and surrounding communities (Veiga et al., 2004). Once the ore has been extracted, small-scale and artisanal mining primarily employ elemental mercury amalgamation to separate gold from the ore (Lacerda, 1997; Veiga et al., 2004). This practice is so prevalent that small-scale and artisanal gold production make up 37% of annual anthropogenic emissions of mercury (UNEP, 2013).

Once emitted by the miner or mineral processor, mercury vapor stays in the atmosphere for up to two years and is distributed across the globe (Seigneur et al., 2004; Swain et al., 2007; Spadaro and Rabl, 2008). Eventually, the mercury vapor is deposited into aquatic sediments where approximately 2% is transformed by microorganisms into methylmercury - a toxic mercury compound that is readily bioavailable (Mergler et al., 2007). Methylmercury bio-accumulates and concentrates in the aquatic food chain to produce dangerous concentrations in large predatory fish that are consumed by humans (Hylander and Goodsite, 2006; Mergler et al., 2007; UNEP, 2013). Consumption of methylmercury contaminated fish impacts the central nervous system and heart (Mcalpine and Araki, 1958; Mergler et al., 2007; Ekino et al., 2007). Globally, mercury emissions have become a top priority as the concentration of mercury in animal tissues has increased dramatically over the last century (UNEP, 2013, pp.29) - see Fig. 1.

The developing brain of a human fetus is particularly susceptible to methylmercury because the fetus has not yet developed the blood-brain barrier (Mcalpine and Araki, 1958; Mergler et al., 2007; Ekino et al., 2007). By consuming contaminated fish several times a week, a pregnant woman can permanently impair the development of her fetus' brain (Mcalpine and Araki, 1958; Mergler et al., 2007; Ekino et al., 2007). Reduction of IQ, as a result of fetal methylmercury poisoning, is one of the best studied impacts of methylmercury (Mergler et al., 2007).

In the early 2000s, regulations were proposed in the United States

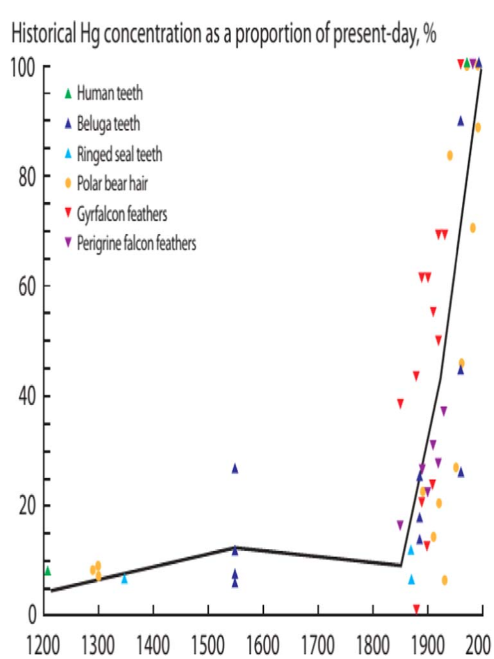

Fig. 1. Historical Total Mercury Concentration in Animal Teeth, Hair, and Feathers as a Percentage of Present-Day Concentration, from UNEP (2013).

to require coal fired power plants to abate their mercury emissions. These regulations spawned attempts to weigh the costs and benefits of mercury emission abatement. Several studies mapped the chain of mercury emission, deposition, conversion to methylmercury, methylmercury bio-accumulation, maternal consumption of contaminated fish, ensuing impact on fetal cognitive functioning and loss of IQ (Seigneur et al., 2004; Rice and Hammitt, 2005; Trasande et al., 2005; Hylander and Goodsite, 2006; Swain et al., 2007; Mergler et al., 2007; Spadaro and Rabl, 2008; Sundseth et al., 2010; UNEP, 2013). In short, these analyses focus on the tiny fraction of elemental mercury that becomes methylated, is ingested from fish fillets by pregnant women, and affects the fetal nervous system. Of these studies, Trasande et al. (2005), Rice and Hammitt (2005), and Spadaro and Rabl (2008) map quantities of mercury emission into lost earnings due to fetal IQ loss to produce monetary estimates of the impact of mercury emissions. A review of the literature suggests that IQ loss - due to the consumption of methylmercury contaminated fish - is the only properly monetized impact estimate relating to mercury emissions (Sundseth et al., 2010). The present analysis uses the monetary estimates from these three studies to estimate the external cost of emission rates from a dozen mine sites around the world.

The majority of mine site information that this analysis relies upon for small-scale and artisanal mining operations comes from the *Global Mercury Project*, which was a joint venture between the University of British Columbia, the World Bank, the United Nations Environment Program, and the United Nations Development Program. The *Global Mercury Project* was conducted at seven sites from 2002 through 2006 with the primary goal of increasing the adoption of measures that reduce mercury pollution from small-scale and artisanal mining. Site data were collected on mercury emissions, gold production, and total mercury levels in sampled populations. Similar information for five additional sites are provided by: a master's thesis on small-scale and artisanal mining in China (Gunson, 2004), evaluations of an artisanal site and a small-scale site in Peru (Iramina et al., 2014; McMahon, 1999; Kuramoto, 2002), and regulatory filings in Nevada (NMCP, 2015) related to two TNMC-owned operations. The availability of data limits the scope of analysis to mercury emissions at these twelve sites.

2. Method

This analysis uses estimates from the environmental economics literature to assign monetary value to environmental impacts of mining. This method, known as benefit transfer, is the practice of applying results from existing environmental valuations to sites with similar pollutants (Bingham et al., 1992; Loomis, 1992; Wilson and Hoehn, 2006). The need for environmental valuation, coupled with the expense of conducting primary valuation studies, has propelled benefit transfer forward as a widely accepted method to approximate the value of environmental services at new locations (Wilson and Hoehn, 2006). Adjustments are often made to scale the original environmental valuation results to ensure that they more accurately reflect the new site's population (Bingham et al., 1992; Loomis, 1992; Wilson and Hoehn, 2006). For example, the magnitude of a valuation result is frequently scaled to reflect differences in income between two populations. This is done because income is an important determinant of the original valuation result.

To estimate the value of mercury emission impacts from mining, this analysis draws from three environmental valuation studies of methylmercury induced fetal IQ loss. The lost earnings estimates from Trasande et al. (2005); Rice and Hammitt (2005), and Spadaro and Rabl (2008) are normalized to reflect the same value per IQ point (which comes from Spadaro and Rabl (2008)). This monetary value per IQ point reflects the global median GDP per capita, adjusted for purchasing power parity [$4640 (2013$)]. Once normalized, the estimates are inflated to 2013 dollars by the consumer purchasing index, divided by the relevant number of kilograms, and presented in