DALLASFED Working Paper

Industrialization and the Demand for Mineral Commodities

Martin Stuermer

Federal Reserve Bank of Dallas
Research Department
Working Paper 1413

Industrialization and the Demand for Mineral Commodities

Martin Stuermer*

December 29th, 2014

Abstract

This paper uses a new data set extending back to 1840 to investigate how industrialization affects the derived demand for mineral commodities. I establish that there is substantial heterogeneity in the long-run effect of manufacturing output on demand across five commodities after controlling for sectoral change, substitution and technological development. My results imply substantial differences across commodities with regard to future demand from industrializing countries and with regard to the effect of demand shocks on prices. Models should include non-Gormand preferences to account for this heterogeneity.

JEL classification: O13, Q31, E23, N50

Keywords: Commodities, non-renewable resources, elasticity of demand, non-homothetic preferences, nonstationary heterogenous panel.

---

*Federal Reserve Bank of Dallas, Research Department, 2200 N. Pearl Street, Dallas, TX 75201, Email: martin.stuermer@dal.frb.org, Tel. +1 214 922 6141. For helpful comments and suggestions, I thank Juergen von Hagen, Martin Hellwig, Joerg Breitung, Friedrich-Wilhelm Wellmer, Felix Wellschmied, Gert Poenitzsch, Gregor Schwerhoff, Frank Pothen, Dirk Foremny, Benjamin Born, Martin Uebele, Alexander Chudik, Julieta Yung, Mine Yucel, Michael Plante, and Ulrich Pfister, as well as participants at the FRESH workshop at the University of Muenster and the 5th World Conference of Environmental and Resource Economics, Istanbul. All remaining errors are mine. I am grateful for editing by Michael Weiss and research assistance by Ines Gorywoda and Achim Goheer. The views in this paper are those of the author and do not necessarily reflect the views of the Federal Reserve Bank of Dallas or the Federal Reserve System. A supplemental appendix is available online at https://sites.google.com/site/mstuermer1/research-1.

1 Introduction

The link between industrialization and the derived demand for mineral commodities such as metals, fuels, and others is critical for understanding commodity price fluctuations (Kilian, 2009; Stuermer, 2013). For example, China's rapid industrialization and its recent slowdown strongly affect commodity prices. Modeling the long-run demand is also important for studying the environmental effects of non-renewable resource use (Acemoglu et al., 2012a), resource wars (Acemoglu et al., 2012b), and for making long-run investments the extractive industries.

However, our current understanding of how industrialization affects the demand for mineral commodities is still very limited. Empirical evidence for the elasticities of demand with regard to output and prices cover only relatively short periods (see Hamilton, 2009; Pei and Tilton, 1999; Kilian and Murphy, 2014, for surveys of the current literature). It does usually not capture the effects of long-term structural changes or technological change in resource efficiency.

Theoretical models typically do not consider the effects of industrialization on the demand for mineral commodities. They assume homothetic preferences, so that the effect of a change in output on the derived demand does not depend on the level of output. This assumption rules out that changes in consumer preferences might affect the product composition and hence the derived demand for individual commodities. For example, at an early stage of industrialization (low per capita manufacturing output), the construction of infrastructure might lead to a product composition that is relatively steel intensive. At a later stage (high per capita manufacturing output), consumers might prefer high tech products that are relatively aluminum intensive.[1]

This paper explores the link between industrialization and the derived demand for mineral commodities from a long-run perspective. It provides empirical evidence that the effect of a change in output on the derived demand for mineral commodities strongly depends on the level of output. This leads to substantial heterogeneity in the consumption paths of mineral commodities. Models with mineral resources need to use non-homothetic preferences to account for this heterogeneity.

I assemble and analyze a new data set that covers 12 countries and five non-renewable resources, namely aluminum, copper, lead, tin, and zinc, for a period extending to 1840. These five base metals have characteristics, such as a substantial track record of industrial use and integrated world markets, which make a long-run analysis possible.

My estimation strategy relies on an extension of the partial adjustment model in a dynamic heterogeneous panel setup following Pesaran et al. (1999). In the baseline specification, I regress derived per capita demand for a commodity on per capita manufacturing output and the relative price of the respective mineral commodity. I control for the effect of sectoral changes by using manufacturing output instead of GDP. In further specifications, I introduce a common linear time trend and time fixed effects in a stepwise manner. This allows me to take advantage of the panel structure of the data and to control for

[1]The literature typically models other mechanisms, namely substitution by other production factors, triggered by relative price changes (see Solow, 1974; Stiglitz, 1974, and the following literature) and technological change in resource use (e.g. Acemoglu et al., 2012a, and others).

omitted common technological change in resource efficiency or new products, which might affect the demand in all countries at the same time.

I find substantial heterogeneity in the long-run effect of a change in per capita manufacturing output on the per capita demand for mineral commodities across five examined commodities. A one percent increase in per capita manufacturing output leads to a 1.5 percent increase in aluminum demand and a one percent rise in copper demand in the long run. Estimated elasticities for lead, tin, and zinc are far below unity. Holding all other factors constant, the intensity use[2] of aluminum in the manufacturing sector increases over the course of industrialization, while the intensity of use of copper is constant, and the intensities of use of lead, tin, and zinc decrease. Common technological trends in resource efficiency and the invention of new products, which are time dependent, have only some negative effect on the demand for aluminum and lead.

Under the plausible assumption that prices of labor, capital, and other production factors are approximately the same across the five different commodities, this heterogeneity is not driven by substitution. My results point to changes in consumer preferences, which alter the product composition of the manufacturing sector over the course of industrialization, and drive the heterogeneity in the the demand for mineral commodities. This mechanism is basically in line with narrative evidence. For example, aluminum is used in many high-tech products, which consumers typically demand at a later stage of economic development. Products that use tin or lead are proportionally more important at an earlier

[2]The "intensity of use" measures how many units of a certain material are used to produce one unit of output (see Malenbaum, 1978; Tilton, 1990, and others)

stage of economic development.

Theoretical models, which might attempt to account for this heterogeneity, should use non-homothetic preferences in modeling the long-run demand for non-renewable resources. For example, the environmental effects of non-renewable resource use would not only depend on endogenous technological change (e.g. Acemoglu et al., 2012a), but also on the level of output. Moreover, the likelihood of resource wars would not only be driven by the price elasticity of demand with (as in Acemoglu et al., 2012b), but also by the elasticity of demand with regard to output. This would also have important policy implications, as non-homothetic preferences focus on the behavior of consumers rather than the supply side. Stefanski (2014) introduces non-homothetic preferences in a growth model with crude oil. However, in this model non-homothetic preferences only drive the inter-sectoral change in demand but not changes in demand within a specific sector like the manufacturing sector. Boppart (2014) provides a general growth model with non-homothetic preferences, which explains structural changes in expenditure by relative prices and income effects. This paper could serve as a valuable starting point for a growth model with non-renewable resources and non-homothetic preferences.

Heterogeneity in the effect of manufacturing output on the demand for mineral commodities also implies large differences in the amplitude of demand shocks on the prices of the examined commodities. For example, an unexpected slowdown in the growth rate of Chinese manufacturing output will have a stronger negative effect on the demand for aluminum or copper than on the demand for zinc, tin, or lead. This observed heterogeneity drives differences in the relative contribution of demand shocks on prices (see Stuermer, 2013) and in overall price volatility across commodities. As the estimated systems adjust to equilibrium in about 7 to 12 years of time, this also contributes to explain the longitude of price fluctuations in these markets (see also Slade, 1991).

The estimated long-run price elasticities of demand are rather inelastic for the examined mineral commodities. Again, there are pronounced differences across the examined mineral commodities. While price elasticity is about -0.7 and -0.8 in the case of aluminum demand, it is about -0.4 for copper demand, and below or equal to about -0.2 for lead, tin, and zinc demand. This shows that these mineral commodities are rather essential to manufacturing output, as the processing industry changes its use slowly in response to price.

My results help firms in the extractive sector define their long-term investment strategies and hence, facilitate for smoother markets. Countries dependent on mineral commodity exports may better judge the long-term perspective of the respective markets and adjust their macroeconomic and fiscal policies accordingly. For example, the estimated manufacturing output elasticities of demand suggest that industrialization in China will cause aluminum demand to increase relative to manufacturing output, while copper will grow in proportion to manufacturing output. The demand for lead, tin, and zinc decreases relative to manufacturing output in the long term.

The paper is structured as follows. Section 2 introduces the data set. Section 3 introduces the econometric model. Section 4 presents the estimation results. Section 5 describes robustness checks, while Section 6 draws conclusions.

2 A new data set

I construct a new panel data set, which allows me to regress annual log demand for a specific commodity on log per capita manufacturing output and log price for the time period from 1840 to 2010. My data set consists of a sample of 12 industrialized countries, Belgium, Finland, France, Germany, Italy, Japan, South Korea, the Netherlands, Spain, Sweden, the United Kingdom (U.K.), and the United States (U.S.). The examined mineral commodities are aluminum, copper, lead, tin, and zinc.[3] These commodities were traded on the London Metal Exchange as fungible and homogeneous goods in an integrated world market over the long period considered here. They exhibit a substantial track record in industrial use. Hence, they have long-term characteristics that other mineral commodities such as iron ore, crude oil, or coal have only gained in recent times and which make a long-run analysis feasible.

The demand for a mineral commodity, the dependent variable, is derived from the output of the manufacturing sector. The demand data capture those quantities of mineral commodities that are finished but unwrought (e.g., metal in primary shapes, such as cathodes and bars), and that manufacturers use at the first stage of production (e.g., brass mills, foundries). This is also the stage at which mineral commodities are usually traded, and it is the usual data set employed for measuring the use of mineral commodities (Tilton, 1990; U.S. Geological Survey, 2011). From 1840 to 1918, I compute the apparent usage

[3]See Table 1 for summary statistics, and the Online-Appendix for detailed data sources and descriptions.

of the respective mineral commodities drawing on production data, as well as import and export data from several sources. Stocks are not included in the computation of usage, due to a lack of data. As this latter measurement error is rather stochastic in nature, coefficients might be underestimated to a certain extent. From the end of World War I to today, I employ data from the German Federal Institute for Geosciences and Natural Resources (BGR 2012a). The data are mainly based on direct surveys of manufacturing industries. It has been rounded by the German Federal Institute for Geosciences and Natural Resources, which might lead to slightly larger standard deviations.

Table 1: Summary statistics.

Variable	Mean	Std. Dev.	Min	Max	N
Per capita GDP (Geary-Khamis $)	8341	6698	860	31618	1454
Per capita value added by manufacturing (GK-$)	1807	1273	83	6565	1414
Per capita use of aluminum (mt/person)	.0068	.0078	.0000	.0490	1094
Per capita use of copper (mt/person)	.0056	.0063	.0000	.0402	1401
Per capita use of lead (mt/person)	.0032	.0018	.0001	.0079	1189
Per capita use of tin (mt/person)	.0002	.0001	.0000	.0008	1292
Per capita use of zink (mt/person)	.0038	.0045	.0000	.0384	1391
Real price of aluminum (local currencies per mt)	1046	5333	.77	140411	1288
Real price of copper (local currencies per mt)	602	1330	0.92	8358	1381
Real price of lead (local currencies per mt)	180	392	.28	2633	1376
Real price of tin (local currencies per mt)	1856	4155	2.53	29042	1368
Real price of zinc (local currencies per mt)	238	518	.47	3798	1364

Please note that these variables enter the regression in logs.

I use per capita value added in the manufacturing sector as explanatory variable. To obtain a comparable measure across countries, I first compute the share of manufacturing in GDP from national account data from several sources. I then multiply these percentage shares with GDP data in constant International Geary-Khamis Dollars[4] from the Maddison (2010) data set, which is a standard data set in the economic history literature. All historical national account data are based on later reconstructions and measurement errors are a potential problem. To the extent that measurement errors are stochastic, estimates will be biased towards zero and underestimate the true value. There might also be systematic measurement errors, whose biases are hard to judge.

To control for the effect of price on demand, I assemble and construct historical prices for each country. I collect price data for the U.S., U.K., and Germany from several sources, but there are no price data series available for the other countries. However, there is strong evidence that the five mineral commodities were traded in integrated world markets with a world market price set in London over the examined time period from 1840 to 2010 (see Klovland, 2005; O'Rourke and Williamson, 1994; Labys, 2008; Stuermer and von Hagen, 2012). I derive proxies for the national prices of the other countries by using historical exchange rates from Bordo (2001), Officer (2006, 2011), Denzel (2010), and others. I compute real prices for each country by using producer price indices from Mitchell (2003a,b, 1998), and other sources. My approach neglects some price differentials due to transport costs. These appear at the price level and decrease gradually over the time period but are considered as not being substantial for these base metals in the above mentioned literature.

[4]The International Geary-Khamis Dollar is a hypothetical unit of currency that allows for international comparison of national accounts across countries and time periods. It relies on purchasing power parity converters and is deflated with the base year 1990.

3 Empirical Strategy

My estimation strategy builds on an extension of the partial adjustment model, which is the standard approach in empirical energy demand analysis (see Adeyemi and Hunt, 2007; Pesaran et al., 1998, 1999). I set up an auto-regressive distributed lag model (ARDL)(p, q, r) of a log linear demand function, where p, q, and r notify the number of lags included of the three explanatory variables:

$$c_{i,t} = \sum_{j=1}^{p} \lambda_{i,j} c_{i,t-j} + \sum_{l=0}^{q} \delta_{i,l} y_{i,t-l} + \sum_{m=0}^{r} \gamma_{i,m} p_{i,t-m} + \mu_i + \epsilon_{it} \ . \tag{1}$$

I explain the demand for mineral commodities $c_{i,t}$ (measured in metric tons per capita) of country i at time t by real per capita value added in the manufacturing sector $y_{i,t}$, by the real price of the respective mineral commodity $p_{i,t}$, and by its own lagged values. To capture proportional effects, I employ natural logs to all variables. I control for the effect of population growth by using per capita manufacturing output, as well as per capita demand of each mineral commodity. Country fixed effects μ_i capture omitted country-specific variables that are time independent. For example, a strong domestic copper mining industry might cause a generally higher level of copper demand in a country as downstream manufacturing specializes in processing copper.

Following Pesaran et al. (1998), I add a common linear time trend in the second specification and time fixed effects in the third specification. This allows me to take advantage of the panel structure of the data in a stepwise manner, and to control for omitted common technological trends and spillover effects (Pesaran et al., 1998). Time fixed effects might also account for a variety of other effects such as the impact of the two world wars on the demand for mineral commodities. As they might also capture changes in world prices, they only leave those price changes in the regression that are due to changes in inflation and exchange rates. If market participants assume that these nominal shocks exhibit no long-term impact on prices, the estimated price elasticity will be small and/or statistically insignificant in specification 3.

Reparametrizing equation (1), I obtain the error correction form of specification 1

$$\begin{aligned}\Delta c_{i,t} &= \Phi_i(c_{i,t-1} - \theta_{0,i} - \theta_{1,i} y_{i,t} - \theta_{2,i} p_{i,t}) \\ &\quad + \sum_{j=1}^{p-1} \lambda^*_{i,j} \Delta c_{i,t-j} + \sum_{l=0}^{q-1} \delta^*_{i,l} \Delta y_{i,t-l} + \sum_{m=0}^{r-1} \gamma^*_{i,m} \Delta p_{i,t-m} + \epsilon_{it} \ ,\end{aligned} \tag{2}$$

where the vector θ_i captures the long-run relationship between the variables. $\theta_{1,i}$ is the long-run elasticity of demand with respect to value added by the manufacturing sector and $\theta_{2,i}$ represents the long-run elasticity of demand with respect to price. Φ_i denotes the speed of adjustment towards the long-run equilibrium.

I use the pooled mean group (PMG) estimator proposed by Pesaran et al. (1999) to accommodate the heterogeneous dynamic of demand functions across countries. Different economic structures across countries may affect the strength and speed at which manufacturing output and price affect the demand for mineral commodities in the short-run. To account for this heterogeneity, the PMG estimator allows the short-run effects to vary across countries, whereas it imposes homogeneity of the coefficients for the long-run effects. The estimated equation in specification 1 becomes

$$\begin{aligned}\Delta c_{i,t} &= \Phi(c_{t-1} - \theta_0 - \theta_1 y_t - \theta_2 p_t) \\ &+ \sum_{j=1}^{p-1} \lambda_{i,j}^* \Delta c_{i,t-j} + \sum_{l=0}^{q-1} \delta_{i,l}^* \Delta y_{i,t-l} + \sum_{m=0}^{r-1} \gamma_{i,m}^* \Delta p_{i,t-m} + \epsilon_{it} \ ,\end{aligned} \tag{3}$$

There is the well-known identification problem in estimating energy demand elasticities. There might be reverse causality running from the demand variable to the price variable. The demand curve will only be identified if national prices closely follow international prices or supply is highly elastic (Pesaran et al., 1998). In this study, domestic prices follow - partly by construction - international prices as these markets have been fairly well-integrated at the global level (see Klovland, 2005; O'Rourke and Williamson, 1994; Labys, 2008; Stuermer and von Hagen, 2012) so that national demand does not affect national prices. In addition, the supply of mineral commodities is highly elastic in the long-run according to Radetzki (2008); Krautkraemer (1998) and others (see also the theoretical argument in Stuermer and Schwerhoff (2012)), and I believe it is therefore plausible to assume that demand from a single country does not cause a long-term change in world market price.

I use unbalanced panel data for each of the five mineral commodities. The time dimension is relatively large, while the cross-sectional dimension is rather small with the number of countries $N = 12$. The incidental parameter problem (Nickell, 1981), which affects dynamic panel data models with small T and large N, is therefore not an issue. The common long-run coefficients of θ_i from the PMG estimator are consistent as long as $T \to \infty$, even if N is small (Pesaran et al., 1999). The ARDL specification makes unit root pretesting of the variables unnecessary. Pesaran and Smith (1995) and Pesaran (1997) show that the method is valid whether or not the variables follow a unit root process. This is based on the assumptions that there is in fact a long-run relationship, that regressors are strictly exogenous, and that there is no serial correlation in the residuals. The existence of a long-run relationship requires the adjustment coefficient to fulfill $-2 < \Phi_i < 0$ (Loayza and Rancière, 2006).

I model the time-fixed effects by expressing all variables as deviations from their respective cross-sectional means in each period in line with Pesaran et al. (1999). Such a procedure reduces common time specific effects and makes PMG estimates consistent. PMG estimation assumes that regression residuals are independent across countries. Non-zero error co-variances may arise due to the omission of these common effects (Pesaran et al., 1999). The disadvantage of including time-fixed effects is that they also control for changes in the world market price, leaving only those price changes in the regression caused by changes in inflation and exchange rates. If market participants assume that these nominal shocks exhibit no long-term impact on prices, the estimated price elasticities will be small and/or statistically insignificant.

Determining the lag order by information criteria on a country-by-country basis reveals significant differences across countries. However, to make regression results for the short-run and long-run parameters comparable, a common lag structure is imposed across countries. The benchmark model is an ARDL(4,4,2) model, with the inclusion of four lags of mineral commodity demand and of manufacturing output, and two lags of mineral commodity prices respectively, in Equation 3. I use a comparatively long lag structure to allow for rich dynamics and to account for possible serial correlation in the data.

I check the robustness of my results with respect to a different choice of lag lengths and the use of other estimators, which impose full heterogeneity and full homogeneity across the coefficients. I present estimation results for ARDL(1,1,1) and ARDL(3,3,3) specifications of Equation 3. Furthermore, I employ the mean group (MG) and the standard dynamic fixed effects (DFE) estimators as robustness checks. The MG estimator proposed by Pesaran and Smith (1995) derives the full panel estimates of θ, Φ, δ, and γ by averaging the individual country coefficients. It imposes no homogeneity restrictions on long-run or short-run restrictions. The DFE estimator restricts the long-run and short-run coefficients as well as the adjustment coefficient, making them equal across the range of countries. The PMG estimator stands between these two estimators with respect to the homogeneity that it imposes. The standard Hausman (1978) test is used, as proposed by Pesaran et al. (1999), to examine if long-run elasticity is, in fact, equal across the countries. If the null hypothesis of equality is not rejected, the PMG estimator is superior to the MG estimator as it is both consistent and efficient in this case, while the MG estimator is only consistent.

4 Estimation results

I find pronounced differences in the estimated long-run elasticities of demand with regard to manufacturing output across the five examined mineral commodities. Table 2 shows the estimation results for the first specification. I find a rather high coefficient in the case of aluminum: a 1.0 percent increase in manufacturing output leads to a more than 1.5 percent increase in aluminum demand. The estimate for copper yields a long-run elasticity of demand with regard to manufacturing output close to unity. The estimated long-run manufacturing output elasticities of lead, tin, and zinc are far below with 0.4, 0.6, and 0.7, respectively.

Table 2: Estimates of the long-run manufacturing output and price elasticities for Specification 1.

	Aluminum	Copper	Lead	Tin	Zinc
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	No	No	No
Manufacturing (log)	1.551***	0.914***	0.435***	0.616***	0.734***
	(0.092)	(0.061)	(0.057)	(0.035)	(0.033)
Price (log)	-0.706***	-0.400***	-0.220**	0.169**	-0.064
	(0.184)	(0.093)	(0.093)	(0.085)	(0.088)
Constant	-0.056	-0.161***	0.048**	-0.522**	-2.04***
	(0.059)	(0.052)	(0.022)	(0.209)	(0.209)
Adjustment coefficient	-0.117***	-0.132***	-0.094***	-0.095**	-0.113***
	(0.023)	(0.028)	(0.021)	(0.040)	(0.055)
Observations	973	1,206	1,059	1,142	1,216
Log likelihood	404.4	502.3	474.7	399.5	579.2

Notes: The table shows results from the pooled mean group (PMG) estimations of the preferred ARDL(4,4,2) model. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

These results imply that the demand for aluminum increases at a higher rate than manufacturing output and, hence, the aluminum demand of the manufacturing sector increases over the course of industrialization. The demand for copper increases approximately at the same rate as manufacturing output. Hence, the copper intensity of the manufacturing sector is relatively constant. The demand for lead, tin, and zinc increases at a lower rate than manufacturing output. The intensity of use of these commodities declines over the course of industrialization.

The estimated elasticities are generally in line with the evidence on the use of the commodities. Aluminum is mainly used for the production of high technology goods such as airplanes, electronics, or machinery. It seems plausible that the demand for these goods increases relatively over the course of industrialization, as consumer preferences shift to high-tech products. Copper is very versatile and the manufacturing sector employs it in the production of a broad variety of products in electronics, construction, and transportation as well as in machinery (see Radetzki, 2009; Mardones et al., 1985). This explains why the overall demand for products that incorporate copper stayed relatively constant. The main appliance of zinc is in galvanization. Its use is strongly linked to products of the steel industry that lose importance as preferences shift over the course of industrialization (see Gupta, 1982; Jolly, 1997). Finally, it seems reasonable that the products, which extensively use tin and lead have a relatively strong demand at the early stages of industrialization but then loose relative importance. Lead is used in the production of a variety of manufactured goods such as pipes and batteries. It is an important alloy, especially in solder (Krebs, 2006). Tin is mainly used in the packaging industry as tinplate, a tin coating on thin steel. It is also employed as an alloy with lead as solder and is applied in different alloys, of which bronze is the most important (Krebs, 2006; Stuermer and von Hagen, 2012). The results suggest that the decreasing use of lead in gasoline, paint pigments, and pipes due to negative health and environmental impacts is substantially driven by a higher per capita manufacturing output and the related change in consumer preferences.

The estimated long-run price elasticities of demand are inelastic for all examined mineral commodities. The estimated long-run price elasticity of aluminum demand is significant and around -0.7. Compared with the other examined mineral commodities, the estimated long-run price elasticity of aluminum demand is relatively high. This is in line with the fact that aluminum has substituted for many different materials such as composites, glass, paper, plastics, copper, and steel in a wide range of appliances in manufacturing production over the course of history (Radetzki, 2008; Chandler, 1990). The estimated long-run price elasticity of demand of copper is rather low with a point estimate of about -0.4 in the first specification. This shows that copper is only moderately substitutable in its major applications. Although aluminum, plastics, and fiber optics have been substitutes for copper, especially in building materials and data transmission, its substitutability is very low in applications as a conductor of electricity (see Krebs, 2006). The estimates for the price elasticities of lead, tin, and zinc demand are far lower than those for copper and aluminum.

I find evidence for the existence of long-run relationships in all regressions. The estimated speed of demand adjustment is rather slow for all commodities. The estimated coefficients suggest a speed of convergence to equilibrium of about 9 to 13 percent per year across the five commodities. This implies that it takes about 7 to 10 years to revert back to equilibrium. This is reasonable, given that adjustments in manufacturing capital are fairly slow and that inventories play an important role in these markets.

In the second specification, I introduce a linear time trend to account for technological change, which drives the demand in all countries at the same time. This might include technological change in resource efficiency or the invention of new products. Introducing a linear time trend, does not affect the pronounced differences in the estimated long-run manufacturing output elasticities of demand, which I find across the five examined mineral commodities, as table 3 shows. Like in specification 1, aluminum has a high estimated long-run manufacturing output elasticity of demand, while lead and tin have the lowest. The estimated coefficients for the linear time trends are all negative and drive down the demand for aluminum by about 1.2 percent per year and the demand for the other commodities by about 0.5 percent per year. Those for copper and lead are statistically significant. This indicates a trend towards resource efficiency in the long run.

Table 3: Estimates of the long-run manufacturing output and price elasticities for Specification 2.

	Aluminum	Copper	Lead	Tin	Zinc
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	No	No	No
Manufacturing (log)	1.759***	1.104***	0.675***	0.712***	0.852***
	(0.173)	(0.145)	(0.110)	(0.080)	(0.101)
Price (log)	-0.883***	-0.453***	-0.215***	0.110	-0.066
	(0.221)	(0.095)	(0.080)	(0.084)	(0.084)
Constant	1.411***	0.474***	0.393***	-0.149	-0.090
	(0.421)	(0.182)	(0.095)	(0.118)	(0.118)
Linear trend	-0.012*	-0.005	-0.005***	-0.004	-0.004
	(0.007)	(0.004)	(0.002)	(0.003)	(0.003)
Adjustment coefficient	-0.113***	-0.131***	-0.121***	-0.105**	-0.119***
	(0.023)	(0.028)	(0.026)	(0.043)	(0.062)
Observations	973	1,206	1,059	1,142	1,216
Log likelihood	405.2	502.8	476.9	400.1	579.8

Notes: The table shows results from the pooled mean group (PMG) estimations of the preferred ARDL(4,4,2) model. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Including a linear time trend does not substantially change estimated coefficients for the long-run price elasticities of demand. The estimated speeds of demand adjustment are slightly lower than in the first specification with a annual rates of 9 to 15 percent.

In the third specification, time fixed effects are employed instead of the linear time trends to control for common shocks from technological change. They also account for other factors, which might affect the demand for these commodities in all countries at the same time, e.g., the two world war periods. The general picture stays the same. There are pronounced differences in the estimated long-run manufacturing output elasticities of demand across the five examined mineral commodities. As before, aluminum has a high estimated long-run manufacturing output elasticity of demand, while lead and tin have the lowest. The one for tin becomes significantly lower than in the other two specifications at about 0.3. As in the specifications before, the estimates of the price elasticities are very low and it takes a long time before demand adjusts to equilibrium.

Table 4: Estimates of the long-run manufacturing output and price elasticities for Specification 3.

	Aluminum	Copper	Lead	Tin	Zinc
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Manufacturing (log)	1.581***	1.128***	0.745***	0.295**	0.834***
	(0.073)	(0.067)	(0.112)	(0.141)	(0.132)
Price (log)	-0.836***	-0.009	-0.014	-0.384***	0.207**
	(0.236)	(0.049)	(0.204)	(0.046)	(0.083)
Constant	0.054	0.010	0.028	0.006	-0.017
	(0.083)	(0.030)	(0.022)	(0.026)	(0.026)
Adjustment coefficient	-0.142***	-0.180***	-0.148***	-0.096***	-0.085***
	(0.031)	(0.057)	(0.033)	(0.030)	(0.022)
Observations	973	1,206	1,059	1,142	1,216
Log likelihood	432.4	434.2	435.3	408.9	518.9

Notes: The table shows results from the pooled mean group (PMG) estimations of the preferred ARDL(4,4,2) model. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

5 Sensitivity analysis

I check the robustness of my results with respect to the use of other estimators and different choices of lag length.

Table 5 compares the results of the pooled mean group estimator (PMG) to those of the mean group (MG) estimator and the dynamic fixed effects (DFE) estimator for the case of copper. The results for the other commodities are in the Online-Appendix.[5] The MG estimator does not impose any homogeneity across slopes and error variances, whereas the DFE estimator assumes homogeneity across all slopes and error variances.

The estimated long-run manufacturing output and price elasticities of demand are relatively robust across the different estimators. As expected, the standard errors of the MG estimates are larger and the coefficients are not often statistically significant. Pooling sharpens the estimates considerably as they are more robust to outliers. In the case of aluminum, the effect of the outlier Belgium is obvious and distorts the estimates. The estimated coefficients for the speed of adjustment are in all cases fairly low but significant.

Joint Hausman tests (see tables in the Online-Appendix) do not reject the hypothesis of homogeneity of all long-run coefficients at conventional levels of significance, when the PMG estimates are compared to the MG estimates. As PMG estimates are more efficient than MG estimates, they ought to be preferred. Overall, the joint Hausman tests provide evidence that the data is not violated by relying on PMG rather than MG estimates for all mineral commodities in the regressions with time-fixed effects (see also Pesaran et al., 1999).

The model is re-estimated using ARDL(1,1,1) and ARDL(3,3,3) configurations (see Tables 6 and 7) for the case of copper and the respective tables in the Online-Appendix for the other commodities studied. Smaller lag lengths yield qualitatively similar results for all mineral commodities except tin, where the price elasticity becomes insignificant

[5]Please find the Online-Appendix at https://sites.google.com/site/mstuermer1/research-1.

in the case of ARDL(3,3,3). The null hypothesis of the Hausman test is not rejected in any of the specifications. The adjustment coefficients are statistically significant in all estimations, showing strong evidence for long-run relationships between variables.

Table 5: Estimation results from the mean group (MG), pooled mean group (PMG), and dynamic fixed effects (DFE) estimators of the preferred ARDL(4,4,2) model for copper.

VARIABLES	MG	PMG	DFE	MG	PMG	DFE	MG	PMG	DFE
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	No	No	No	No	Yes	Yes	Yes
Manufacturing (log)	1.053***	0.914***	1.080***	1.020***	1.104***	1.091***	0.932***	1.128***	1.164***
	(0.175)	(0.061)	(0.087)	(0.188)	(0.145)	(0.178)	(0.341)	(0.067)	(0.173)
Copper price (log)	-0.097	-0.400***	-0.142	-0.177	-0.453***	-0.145	-0.523	-0.009	0.222**
	(0.176)	(0.093)	(0.176)	(0.125)	(0.095)	(0.182)	(0.440)	(0.049)	(0.101)
Linear trend				0.006	-0.005	-0.000			
				(0.005)	(0.004)	(0.004)			
Constant	-0.754***	-0.161***	-0.387***	-3.733*	0.474***	-0.366	0.094	0.010	0.003
	(0.229)	(0.052)	(0.134)	(2.021)	(0.182)	(0.334)	(0.137)	(0.030)	(0.006)
Adjustment coefficient	-0.200***	-0.132***	-0.102***	-0.236***	-0.131***	-0.102***	-0.240***	-0.180***	-0.114***
	(0.039)	(0.028)	(0.015)	(0.036)	(0.028)	(0.015)	(0.064)	(0.057)	(0.016)
Observations	1,206	1,206	1,206	1,206	1,206	1,206	1,206	1,206	1,206
Joint Hausman Test-stat.		3.799			98.01			1.693	
p-value		0.150			0			0.429	
Log likelihood		502.3			502.8			434.2	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Estimated long-run manufacturing output and price elasticities of copper demand in the ARDL(1,1,1) model using the mean group (MG), the pooled mean group (PMG), and the dynamic fixed effects (DFE) estimators.

VARIABLES	MG	PMG	DFE	MG	PMG	DFE	MG	PMG	DFE
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	No	No	No	No	Yes	Yes	Yes
Manufacturing (log)	1.098***	1.055***	1.097***	1.392***	0.983***	1.113***	0.859***	1.165***	1.248***
	(0.193)	(0.039)	(0.097)	(0.249)	(0.095)	(0.206)	(0.306)	(0.072)	(0.210)
Copper price (log)	-0.182	-0.219***	-0.201*	-0.205*	-0.208***	-0.205*	0.188	0.053	0.232
	(0.121)	(0.072)	(0.107)	(0.115)	(0.071)	(0.107)	(0.201)	(0.051)	(0.157)
Constant	-1.097***	-0.524***	-0.483***	-0.097	-0.742***	-0.443	0.075	0.010	0.007***
	(0.284)	(0.107)	(0.169)	(1.719)	(0.146)	(0.725)	(0.077)	(0.029)	(0.002)
Linear trend				-0.004	0.002	-0.000			
				(0.006)	(0.002)	(0.006)			
Adjustment coefficient	-0.238***	-0.168***	-0.132***	-0.274***	-0.168***	-0.132***	-0.253***	-0.199***	-0.145***
	(0.032)	(0.030)	(0.026)	(0.033)	(0.032)	(0.027)	(0.047)	(0.051)	(0.029)
Observations	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253
Joint Hausman Test-stat.		0.161			15.28			2.332	
p-value		0.923			0.00159			0.312	
log likelihood		352.8			353.1			305.1	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Estimated long-run manufacturing output and price elasticities of copper demand in the ARDL (3,3,3) model using the mean group (MG), pooled mean group (PMG), and dynamic fixed effects (DFE) estimators.

VARIABLES	MG	PMG	DFE	MG	PMG	DFE	MG	PMG	DFE
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	No	No	No	No	Yes	Yes	Yes
Manufacturing (log)	1.117***	0.963***	1.063***	1.142***	1.399***	1.053***	0.957***	1.047***	1.131***
	(0.160)	(0.055)	(0.085)	(0.139)	(0.097)	(0.175)	(0.321)	(0.063)	(0.177)
Copper price (log)	-0.096	-0.285***	-0.116	-0.130	-0.468***	-0.113	-0.139	-0.041	0.263**
	(0.142)	(0.087)	(0.174)	(0.130)	(0.065)	(0.181)	(0.290)	(0.053)	(0.102)
Constant	-0.924***	-0.291***	-0.395***	-3.604*	1.514***	-0.416	0.170	0.017	0.005
	(0.218)	(0.059)	(0.134)	(2.176)	(0.586)	(0.341)	(0.170)	(0.028)	(0.006)
Linear trend				0.002	-0.012***	0.000			
				(0.004)	(0.003)	(0.004)			
Adjustment coefficient	-0.217***	-0.141***	-0.105***	-0.241***	-0.147***	-0.105***	-0.259***	-0.179***	-0.112***
	(0.048)	(0.028)	(0.015)	(0.047)	(0.041)	(0.015)	(0.067)	(0.049)	(0.016)
Observations	1,213	1,213	1,213	1,213	1,213	1,213	1,213	1,213	1,213
Joint Hausman Test-stat.		2.827			20.72			0.125	
p-value		0.243			0.000120			0.939	
log likelihood		481.2			485.1			427.5	

Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

6 Conclusion

This paper provided empirical evidence on the effect of industrialization on the derived demand for mineral commodities in a new data set extending back to 1840 After controlling for sectorial shifts, substitution, price, and technological change, I find substantial heterogeneity in the estimated long-run effects of manufacturing output on the demand across commodities. A one percent increase in per capita manufacturing output leads to a 1.5 percent increase in aluminum demand and a one percent rise in copper demand. Estimated elasticities for lead, tin, and zinc are far below unity. Common technological trends in resource efficiency and the invention of new products, which are time dependent, have some effect on the demand for aluminum and lead. This heterogeneity points to changing consumer preferences which alter the product composition of the manufacturing sector and thereby affect the derived demand for mineral commodities differently during the process of industrialization.

My results suggest that models, which include mineral commodities or non-renewable resources, need to include non-homothetic preferences to account for this heterogeneity. They also imply large differences in the amplitude of demand shocks across the different examined commodities. This contributes to explain differences in price volatility across commodities. As the estimated systems adjusts to equilibrium in about 7 to 12 years of time, this also helps to explain the longitude of price fluctuations in these markets. The estimated long-run price elasticities of demand are highly inelastic for the examined mineral commodities. This show that these mineral commodities are rather essential to manufacturing output as the processing industry changes its use slowly in response to price.

Finally, my results imply substantially different paths of consumption of mineral commodities by emerging economies such as China. A slow down in the growth rate of Chinese manufacturing output will have a stronger negative effect on the demand for aluminum or copper than for zinc, tin, or lead. At the same time, total consumption of lead, tin, and zinc will grow at a lower rate in the long run than the one of copper and aluminum, because lead, tin and zinc have a decreasing material intensity of use over the course of industrialization.

References

Acemoglu, D., Aghion, P., Bursztyn, L., and Hemous, D. (2012a). The environment and directed technical change. *American Economic Review*, 102(1):131–66.

Acemoglu, D., Golosov, M., Tsyvinski, A., and Yared, P. (2012b). A dynamic theory of resource wars. *The Quarterly Journal of Economics*, 127(1):283–331.

Adeyemi, O. and Hunt, L. (2007). Modelling OECD industrial energy demand: asymmetric price responses and energy-saving technical change. *Energy Economics*, 29(4):693–709.

BGR = Federal Institute for Geosciences and Natural Resources (2012). *Database on the use of mineral commodities.* Federal Institute for Geosciences and Natural Resources (Bundesanstalt fuer Geowissenschaften und Rohstoffe), Hanover.

Boppart, T. (2014). Structural change and the Kaldor facts in a growth model with relative price effects and non-Gormand preferences. *Econo*, 82(6):pp. 2167–2196.

Bordo, M. (2001). Financial crises. Lessons from the last 120 years. *Economic Policy*, 16(32):51–82.

Chandler, A. D. (1990). *Scale and scope.* The Belknap Press of Harvard University Press, Cambridge, M.A., and London.

Denzel, M. (2010). *Handbook of world exchange rates, 1590-1914*. Ashgate, Farnham.

Gupta, S. (1982). *The world zinc industry*. Lexington Books, Lexington, M.A.

Hamilton, J. (2009). Understanding crude oil prices. *The Energy Journal*, 30(2):179–206.

Hausman, J. (1978). Specification tests in econometrics. *Econometrica*, 46(6):1251–1271.

Jolly, J. (1997). *US zinc industry: a history, statistics, and glossary*. American Literary Press, Baltimore.

Kilian, L. (2009). Not all oil price shocks are alike: disentangling demand and supply shocks in the crude oil market. *American Economic Review*, 99(3):1053–69.

Kilian, L. and Murphy, D. P. (2014). The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics*, 29(3):454–478.

Klovland, J. (2005). Commodity market integration 1850-1913: evidence from Britain and Germany. *European Review of Economic History*, 9(02):163–197.

Krautkraemer, J. (1998). Nonrenewable resource scarcity. *Journal of Economic Literature*, 36(4):2065–2107.

Krebs, R. (2006). *The history and use of our earth's chemical elements: a reference guide*. Greenwood Publishing Group, Westport, C.T.

Labys, W. (2008). *Modeling and Forecasting of Primary Commodity Prices*. Ashgate, Burlington.

Loayza, N. and Rancière, R. (2006). Financial development, financial fragility, and growth. *Journal of Money, Credit and Banking*, 38(4):1051–1076.

Maddison, A. (2010). Historical statistics of the world economy: 1-2008 AD. http://www.ggdc.net/maddison/ (accessed on June 13, 2011).

Malenbaum, W. (1978). *World demand for raw materials in 1985 and 2000*. McGraw-Hill, New York.

Mardones, J., Silva, E., and Martinez, C. (1985). The copper and aluminum industries: a review of structural changes. *Resources Policy*, 11(1):3–16.

Mitchell, B. (1998). *International historical statistics: Africa, Asia & Oceania, 1750–1993*. Palgrave Macmillan, Hampshire, N.Y.

Mitchell, B. (2003a). *International historical statistics: Europe, 1750–2000*. Palgrave Macmillan, Hampshire, N.Y.

Mitchell, B. (2003b). *International historical statistics: the Americas, 1750–2000*. Palgrave Macmillan, Hampshire, N.Y.

Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica*, 49(6):1417–1426.

Officer, L. (2006). Bilateral exchange rates. europe: 1913-1999. In *Historical statistics of the United States: Millennial edition*. Cambridge University Press, Cambridge.

Officer, L. (2011). Exchange rates between the united states dollar and forty-one currencies. http://www.measuringworth.com/exchangeglobal/ (accessed October 20, 2011).

O'Rourke, K. and Williamson, J. (1994). Late nineteenth-century Anglo-American factor-price convergence: were Heckscher and Ohlin right? *The Journal of Economic History*, 54(4):892–916.

Pei, F. and Tilton, J. (1999). Consumer preferences, technological change, and the short-run income elasticity of metal demand. *Resources Policy*, 25(2):87–109.

Pesaran, M. (1997). The role of economic theory in modelling the long run. *The Economic Journal*, 107(440):178–191.

Pesaran, M., Shin, Y., and Smith, R. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, 294(446):621–634.

Pesaran, M. and Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, 68(1):79–113.

Pesaran, M., Smith, R., and Akiyama, T. (1998). *Energy demand in Asian developing countries*. Oxford University Press, Oxford, U.K.

Radetzki, M. (2008). *A handbook of primary commodities in the global economy*. Cambridge Univ. Press, Cambridge, U.K.

Radetzki, M. (2009). Seven thousand years in the service of humanity: the history of copper, the red metal. *Resources Policy*, 34(4):176–184.

Slade, M. (1991). Market structure, marketing method, and price instability. *The Quarterly Journal of Economics*, 106(4):1309–1340.

Solow, R. M. (1974). The economics of resources or the resources of economics. *The American Economic Review*, 64(2):pp. 1–14.

Stefanski, R. (2014). Structural Transformation and the Oil Price. *Review of Economic Dynamics*, 17(3):484–504.

Stiglitz, J. (1974). Growth with exhaustible natural resources: efficient and optimal growth paths. *The Review of Economic Studies*, 41:123–137.

Stuermer, M. (2013). 150 years of boom and bust. What drives mineral commodity prices? *Discussion Paper of the German Development Institute*, (2013/05).

Stuermer, M. and Schwerhoff, G. (2012). Non-renewable but inexhaustible resources in an endogenous growth model. *Preprints of the Max Planck Institute for Research on Collective Goods Bonn*, (2012/09).

Stuermer, M. and von Hagen, J. (2012). Der Einfluss des Wirtschaftswachstums aufstrebender Industrienationen auf die Märkte mineralischer Rohstoffe. DERA Rohstoffinformationen 12, Deutsche Rohstoffagentur (DERA) in der Bundesanstalt für Geowissenschaften und Rohstoffe, Berlin.

Tilton, J. (1990). *World metal demand: trends and prospects.* Resources for the Future Press, Washington, D.C.

U.S. Geological Survey (2011). *Historical statistics for mineral and material commodities in the United States.* U.S. Geological Survey, Reston, V.A.