MOTIVATING SUSTAINABLE MATERIAL USE THROUGH INDUSTRY-LEVEL SIMULATION MODELING OF PLATINUM STOCKS AND FLOWS

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Abstract

Manufacturing firms that rely on finite resources have a stake in ensuring sustainable materials use. Higher material prices and uncertain material supply, consequences associated with scarcity, can be damaging to firms. Firms have a number of options to improve material sustainability including dematerialization, material substitution and recycling. However, these options require technological capability, capital investments and supply-chain infrastructure; firms may decide to make such investments only if material prices increase. Once decisions are made, the barriers and delays to implementing changes may harm firms. The impact of not reacting to changes in material supply on firms was examined for the case of different platinum-using industries. It was found that taking action is particularly important for firms when limited material availability leads to volatile market conditions. Industries can benefit especially if they ensure process flexibility and have options for changing their material use patterns.

Introduction

Consideration of materials sustainability not only involves environmental and social concerns, but also business and supply-chain logistics concerns. This paper examines concerns that are relevant for industrial firms that depend on a reliable supply of materials for their manufacturing processes. Such concerns can include minimizing materials costs, ensuring sufficient supply to meet manufacturing demand and minimizing uncertainty of expenditures. Efficient and sustainable use of materials can address those concerns

It has been noted that since many of the costs of materials use are not borne by private firms, the motivation to do more to improve eco-efficiency is inadequate [1]. Still, previous work in the field of industrial ecology has examined how manufacturers can and have found ways to move towards a more closed-loop system in order to reduce costs and increase revenues [2, 3]. In the classic example, multiple firms have been co-located in an industrial park in Kalundborg, Denmark so that the waste products from one firm can be used by another as an input [4]. A historical case study has also shown that when scarcity is an issue, manufacturers take actions to increase their use of secondary materials and substitute with more available materials [5]. In short, taking actions such as recycling, substitution and dematerialization can help manufacturers not only reduce the impact of scarcity on themselves, but also increase sustainability of a material system by decreasing demand and moving towards a more closed-loop system.

Unfortunately, responses for addressing scarcity are not universally applicable, require advance planning, may require labor and capital investments, and do not all have the same effect if implemented. This paper explores manufacturing changes in the form of technological responses such as the use of recycling and dematerialization and the potential benefits from their implementation on industries that use platinum.

Methodology

A system dynamics simulation is used to represent the platinum market as a system of non-linear first-order differential equations. The model employs data on platinum supply and demand, and information about material market behavior, to simulate platinum supply, demand and price endogenously (see **Figure 1**). In this case study, primary and secondary supply can be used interchangeably to meet total platinum demand. Since the structure of the model has been described previously [6], this section will focus on describing the demand sector of the model and the ways in which manufacturing firms' concerns will be captured.

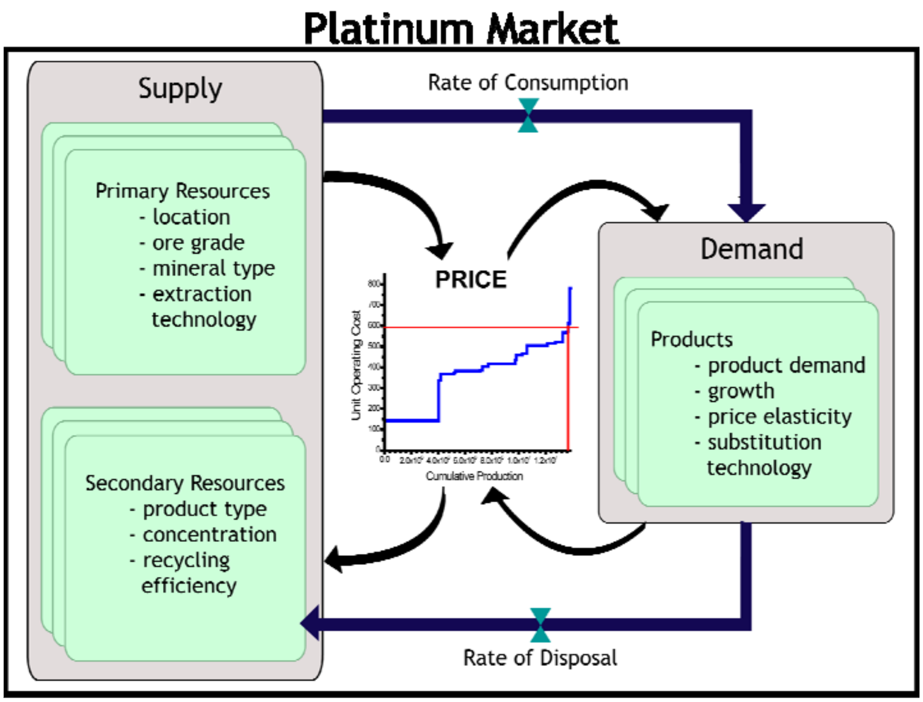

Figure 1. Market model structure diagram with three sectors: Supply, Demand and Price. Straight arrows with valves identify platinum flow from supply to demand and returning to supply. Curved arrows indicate information feedbacks: an increase in supply leads to a decrease in price following a delay, which then leads to a decrease in supply following another delay; similarly, increasing demand leads to increasing price, which leads to decreasing demand.

Platinum is used to make products such as jewelry, hard disks, and automotive catalysts. The total demand for platinum is derived in the model by aggregating demand from seven product categories: jewelry, automotive, electronics, chemical uses, petroleum catalysis, glass, and other. In 2008, automotive and jewelry were the two largest primary platinum use categories, estimated to account for 50 to 60% and 5 to 17% of total primary platinum use, respectively [7, 8].

For each platinum product category, the demand sector uses price elasticity, delay time to implement changes in use patterns and growth of demand expectation values calibrated from historical annual data (1975 to 2008 data). Except for the automotive sector, the historical data on platinum demand reports only primary platinum use. Therefore, global recycling rates were estimated based on product recovery rates, average lifetimes and year of introduction of the product [9-11]. Total platinum demand could then be estimated as the sum of recycled platinum and primary platinum sales for each sector.

For future growth of demand, a number of possible scenarios have been envisioned, although only some results will be presented here. It is possible that growth in the future will follow historical patterns. Platinum use has grown almost exponentially over the past 34 years, driven largely by a regulatory push for lower emission cars and the introduction of the automotive catalytic converter in the late 1970's. Automotive use of platinum went from accounting for less than 15% of total primary platinum use to more than 50% in the past 34 years as nations around the world not only adopted new regulations for automotive emissions but also significantly increased the size of their fleets. An example where future exponential growth for platinum could be envisioned is if new uses of platinum become commercialized and adopted worldwide, such as proton-exchange membrane fuel cell (PEM-FC) vehicles.

Future demand could also be linear, flat or even negative. Metals such as lead, cadmium and tin have had linear or almost flat growth over the past 50 to 100 years. In two of these three cases (lead and cadmium), strong regulation surrounding their use because of their negative health and environmental impacts forced manufacturers either to move towards a very closed-loop system (high recycling of lead automotive batteries) or to avoid using them (lead and cadmium in electronics sold in the European Union because of the RoHS directive). In the case of tin, better substitutes or ways to use less tin for the same application were found (tin food containers replaced by stainless steel or tin-plated stainless-steel). While it is unlikely that platinum demand will decline in the future, several factors indicate a possible slowdown of demand growth. First, while platinum remains the main metal for use in automotive catalytic converters, new trends indicate a possible decrease in the amount of platinum needed per car. Technologies such as use of nanomaterials in the catalytic converters can contribute to a reduction in the use of platinum per vehicle [12]. Changes in use patterns for petroleum as oil prices increase or as greenhouse gas emissions become regulated could also lead to a decrease in the growth rate of platinum use in the petroleum industry.

In the model, we assume that the future demand for platinum will come from the 7 platinum categories that have already been outlined. Moreover, we assume that the largest drivers that would lead to changes in demand for platinum are the price of platinum and demand for products that contain platinum. It is also important to note that in reality, economic growth is not steady and only with a simulation model can growth be projected to follow a steady path. In the model, two scenarios are examined: smooth growth and growth with an unexpected perturbation in the supply side of the system.

Set-up for Scenarios to be Examined

The results of the simulation model are all qualitative. The model does not attempt to predict future platinum prices but instead is designed as an experimental platform for exploring the dynamics of metal markets in the face of scarcity risks. The model was calibrated with historical time-series data of global demand, supply and price. The parameters determined from the calibration are used going into the future, except where exploration of variables is desired. In such cases, changes are made to the model going forward in time and their impact on projected future results is explored.

The base case conditions for the model are as follows:

- 50 year time frame, with 1/32nd year simulation time steps
- 8 primary supply groups (mining regions)
- 7 demand groups (jewelry, automotive, electronics, petroleum catalyst, chemical industry, glass, other)
- 7 recycling supply groups (same categories as for demand groups)
- smooth exponential exogenous growth of product demand: demand changes also depend on price
- initial primary demand: 230 tonnes/year,
- initial base case static recycling rate: secondary supply/total supply = 40%
- price is inflation-adjusted to producer price index for metals and metal products

Table I. Description of conditions for simulation scenarios.

Case	Supply Perturbation	Price Elasticity
A	none	base case
B	1 year shutdown of 50% of primary supply	base case
C	none	automotive elasticity = 1
D	none	automotive recovery rate = 0.8

For Case B, sensitivity analysis of the supply shutdown timing is performed with 200 runs with a randomly selected shutdown start time.

Results and Discussion

Measuring Impacts on Manufacturers

As mentioned previously, concerns of manufacturers include minimizing materials costs, ensuring sufficient supply to meet manufacturing demand and minimizing uncertainty of expenditures. These concerns are explored by using the simulation model to examine a number of factors that impact firms: price of material, expenditures on materials, and variability of price and expenditures.

Expenditures for total platinum use can be defined at each time period, t, as: $Price_t * Purchase_t$

Total expenditures can be summed up from each time period as: $\sum_{t=0}^{T} Expenditures_t$

Average unit expenditures can be calculated as: total expenditures up to a given time divided by total platinum used over the same time period. Variability in price will be examined by measuring the standard deviation of price over the 50-year modeling period, or by comparing price to a smoothed price calculated from a moving average over a 10-year peiod (5 years before and 5 years average).

For scenarios A and B, price, marginal producer cost and smoothed average price are compared in **Figure 2**. For Case B, the example shown is with a shutdown start time in year 15, although sensitivity analysis was performed to examine different shutdown times. In this scenario, smooth and continuous exponential growth of product demand results in a relatively smooth and steady increase in price as primary supply has to continuously grow and tap into lower quality ores to meet demand. Although not plotted here, Case A marginal cost increases almost 5-fold due to degradation of ore grade.

The price increase is large but not unreasonable, at least by historical terms (the platinum real price in 2008 was about 3 times greater than the 1960 real price). The projected demand growth for this model scenario is considered aggressive and a slower growth rate or greater platinum ore discovery rate than the modeled rate would lead to smaller price increases.

The price increase as a result of the perturbation in supply is also very large. In the graphed case, with the perturbation starting in year 15, the price triples. Again, by historical terms, this is not unreasonable. There have been perturbations in other commodity markets that have led to larger increases in price (ex. Cobalt). Perturbations in the supply of a material generally lead to price increases, although the magnitude of the increase varies depending on a number of conditions such as tightness of supply and price elasticity of demand. For example, if a perturbation occurs during a period of time of fast growth of demand and tight supply, the magnitude of price increase will be larger. What is important is that the impact on manufacturers who use that material will depend on the severity of the perturbation and the resulting change in price.

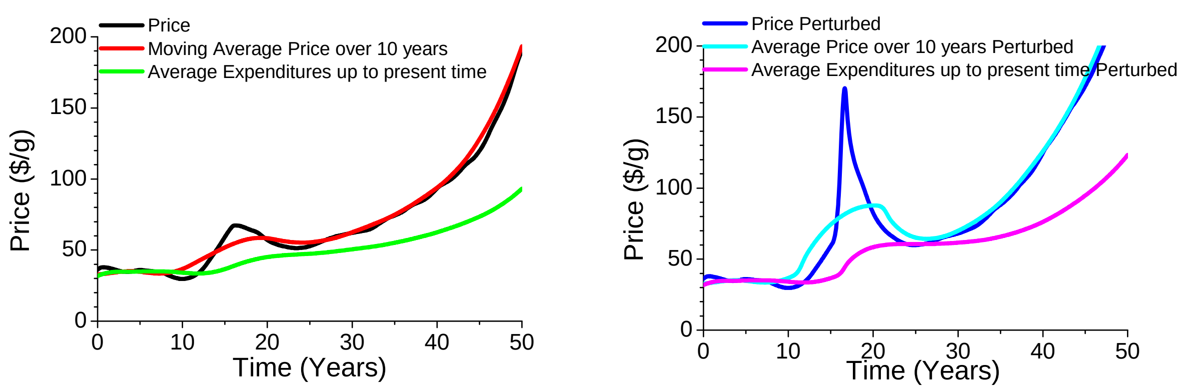

Figure 2. Price, 10-year moving average of price and average overall unit expenditures for the base case, Case A (left), and the case with supply perturbation, Case B (right).

All else being equal, an increase in price will result in an increase in expenditures. However, other factors need to be considered such as growth rate of product demand, price elasticity and delay time to change material use patterns to consider. These three factors were exogenous variables in the model. When demand for products that use platinum is increasing, an increase in expenditures for the industries that need platinum to make those products is expected and not considered detrimental since the increase in expenditures does not correspond to an increase in product unit costs. On the other hand, an expenditure increase that is a result of price increases is potentially detrimental. Depending on price elasticity and the delay time to implement changes, different manufacturers will experience different changes in their expenditures for a given change of price. For this model, high price elasticity can be understood to indicate that an industry will move towards lower use of platinum when prices increase. However, the model also has a delay factor which can prevent immediate changes in the use patterns. In Cases A and B, the increasing price and increasing demand resulted in an overall increase in expenditures over time.

Average unit expenditures are measured for the 50-year modeling period for the overall platinum-using industries and for each industry category (Table II). In Cases A and B, differences between the average unit expenditures of the different industry categories were dependent mainly on underlying product growth rate and price elasticity (exogenous variables). Higher product growth rate resulted in higher average unit expenditures. Increased demand in the later periods gave more weight to expenditures made in the later modeling years, a period of higher prices. This can be illustrated by comparing the chemical and petroleum industries which both have similar elasticity, but petroleum has higher product growth rate and higher average unit expenditure. Higher price elasticity allowed industries to reduce demand as price increased and therefore resulted in lower average unit expenditures. This can be illustrated by comparing the automotive and jewelry industries. While the automotive industry has higher product growth rate, the price elasticity is much smaller.

Overall average unit expenditures were higher in Case B than in Case A due to the higher average price from the perturbation in Case B. The average unit expenditure increase was lowest for the chemical industry and highest for the glass industry. Higher price elasticity and lower product demand growth resulted in a lower % increase in expenditures from the perturbation. The three lowest % increases are experienced in the three industries with highest price elasticity while the three highest % increases are in the three industries with lowest price elasticity.

Table II. Industry-level results for Case A and Case B.

Demand Category	Product Growth Rate (%/yr)	Price Elasticity	Ave. Unit Expenditures over 50yrs **Case A** ($/g)	Ave. Unit Expenditures over 50yrs **Case B** ($/g)	% Increase due to Perturbation
Overall	5.2	N/A	93.2	115	23.4
Chemical	0	0.42	66.7	78.8	18.2
Jewelry	3.2	0.55	76.9	92.2	19.9
Petroleum	1.7	0.48	74.3	89.3	20.2
Electronics	1.1	0.05	72.9	87.9	20.6
Auto	5.6	0.10	94.2	117	24.2
Glass	6.7	0.05	99.0	124	24.7

Focus on an Individual Industry

For Case C, the price elasticity for the automotive industry was increased to 1 and all other variables were kept the same as for Case A. The automotive industry accounts for more than 50% of primary use of platinum and is an industry that is expected to grow rapidly. A change in the price elasticity of platinum for this industry has an effect on the overall price of platinum over the 50-year model period (Figure 3). Although demand for automobiles increase at the same rate (growth rate of *product* demand) for Cases A and C, in Case C, the automotive industry decreases its use of platinum per vehicle as prices increase. In the model, this represents a change that may be accomplished through dematerialization or material substitution.

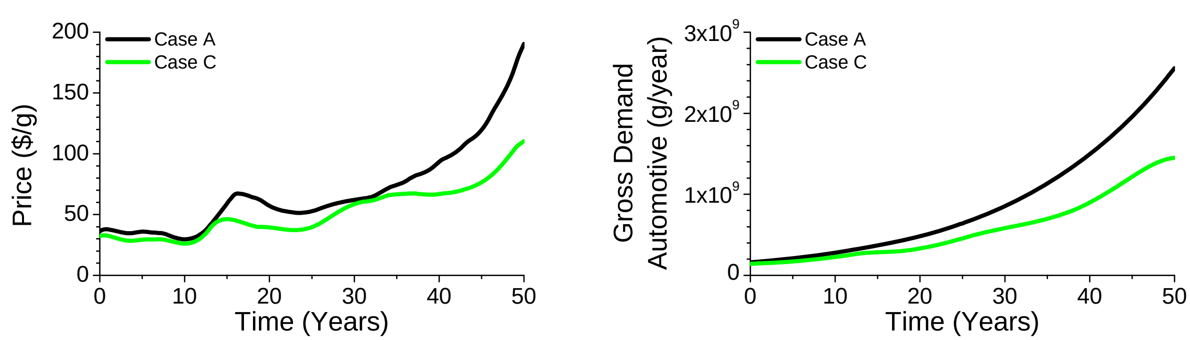

Figure 3. Price and gross demand for platinum in the automotive industry for the base case where automotive price elasticity is 0.1, Case A (left), and the case where automotive price elasticity is 1, Case C (right).

As a result of the decrease in demand for platinum, price does not increase as quickly in Case C. This is a result of reduced growth of demand for primary platinum ores and reduced depletion of ore quality. The decrease in the average price as a result of reduced demand for platinum in the automotive industry benefits the automotive industry and all other industries, which all experience the lower prices. The effect of changing the price elasticity was examined across a range from 0.05 to 1, with 200 points sampled randomly. On average, price and average unit expenditures decreased with increasing price elasticity. A linear fit to the data measures a slope of -19.9 for price, and a slope of -34.8 for average unit expenditure.

For Case D, the fraction of platinum from end-of-life automotives collected was increased from 0.34 to 0.8, more than double. By doubling the amount collected from the automotive industry, the total amount recycled increased by 20%. Gross demand for platinum did not change significantly and the main effect of increasing recycling was a decrease in primary extraction (see Figure 4). Fewer mines were required and there was less depletion of primary ore. The effect of changing the recovery rate on price was examined across a range from 0.05 to 0.9, with 200 points sampled randomly. On average, price decreased with increasing recovery. A linear fit to the data measures a slope of -22.7.

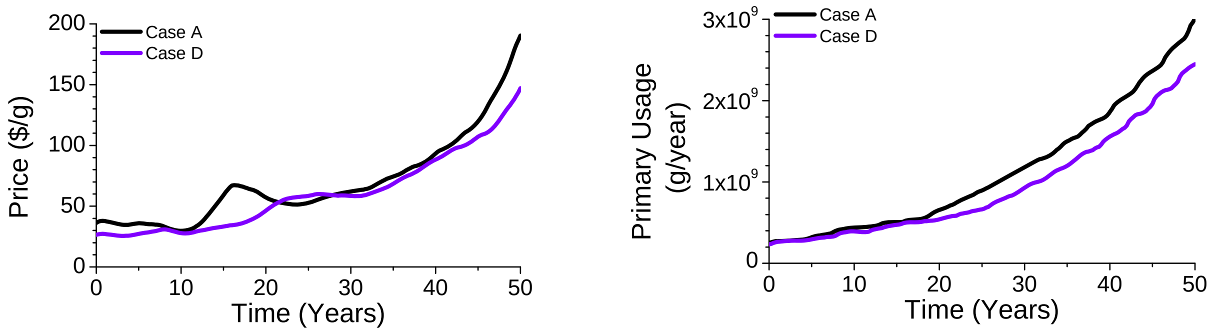

Figure 4. Price and platinum recycled from automotive for the base case where automotive recovery rate is 0.34, Case A (left), and the case where automotive recovery rate is 0.8, Case D (right).

Conclusions

This analysis focused mainly on one factor that is indicative of an industry's ability to implement changes in use patterns following changes to material availability: price elasticity of material demand. Industries with available substitutes for the materials that they use will have higher price elasticity than those without. Dematerialization is another method for firms to change their use patterns in the face of changing material availability.

Industries with higher price elasticity will be more flexible when changes occur in material availability. The model showed that those industries will experience lower average unit expenditures and smaller increases in average unit expenditures when perturbations in supply occur.

An additional potential effect of higher price elasticity is that use of platinum in the industry with higher elasticity decreased when prices increased. A reduction in use of platinum resulted in a lower rate of primary ore depletion and reduced tightness of supply. While prices still increased over time in the case of future exponential growth in demand for products that use platinum, the increase was less steep in the case where a large demand industry's price elasticity increased.

The effect of reduced platinum use in the automotive industry on price was significant. Lower platinum prices benefit all industries that use platinum.

Further examination of the effect of changes in the automotive industry was in the area of recycling. Rather than reduce the demand for platinum, increased recycling of automotive end-of-life platinum reduced the amount of primary extraction by substituting primary for secondary material. The net effect was still a reduction in primary ore depletion and hence price of platinum.

This analysis has measured the benefits of taking actions to change use patterns in the face of changing material availability. However, the costs were not measured. For certain industries, such as the jewelry industry, the cost of substitution is simply the cost of the lower priced material as there would be minimal changes required in the processing and forming of the jewelry. In the case of other industries, there may be research and capital costs. For example, for the automotive industry, dematerialization has required investment into research and development of new nanoparticle catalyst designs. The benefits that are identified need to be weighed against these costs.

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