A Case Study of the Availability of Platinum Group Metals for Electronics Manufacturers

Elisa Alonso, Frank R. Field, Randolph E. Kirchain

Abstract—**Platinum group metals, a key material group for electronics manufacturers, exhibit characteristics of a material with high scarcity risk based on Malthusian, Ricardian and structure metrics. This includes high potential future demand growth, high extraction costs and high market concentration of primary supply. The conditions that impact downstream firms are explored through the use of a dynamic material market model. In particular, the average spending over a period of time by downstream firms is proposed as a simple metric to compare the relative impacts of various scenarios on these firms. One scenario comparison showed that recycling could lower average spending as well as reduce price variance.**

Index Terms—**material scarcity, material availability, supply risk, platinum.**

I. Introduction

THE focus of this paper is an examination of scarcity risks for electronics firms that use platinum group metals (PGMs: platinum, palladium, rhodium, iridium and ruthenium). Although firms have been cited for their impact on scarcity [1], [2], previous work by the authors has shown that the complement is also true: scarcity of materials can negatively impact firms through price surges [3]. In a case analysis of cobalt scarcity in the 1970s, increased costs to private firms led to increased recycling, substitution and reduced material usage. An uprising in Zaire resulted in a serious concern for cobalt supply in large part because 40% of global cobalt land reserves were concentrated there. Market concentration and other metrics gleaned from literature can be used as a first pass comparator for the level of risk of scarcity of different metals. In this paper, metrics showing high risk for platinum are analyzed in more detail with an ordinary differential equations simulation model. This technique has previously been used to gain insight into the behavior of systems with complex feedbacks such as material markets and the supply chain [4]-[8].

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II. Scarcity Metrics

The first step for firm decision-makers is to identify vulnerable elements of their own supply chains. Metrics to signal scarcity can be used by firms to properly allocate resources towards reducing their risks. A number of conventional metrics can be used to signal one of two mechanisms that can result in scarcity: physical constraints and institutional inefficiency (see Table 1). A measure of reserves with respect to primary consumption rates is a Malthusian metric, and a measure of energy costs is a Ricardian metric. Both Malthusian and Ricardian metrics signal physical scarcity. Both market concentration, a structure metric, and recycling rate, a reclamation metric, signal institutional inefficiency.

Price is traditionally a Ricardian metric, but here it is listed separately, because it is also a measure of institutional efficiency (e.g. price volatility).

When firms consider their risks to future materials scarcity, physical constraint metrics indicate potential limitations in the amount and quality of a resource readily available whereas institutional inefficiency metrics can indicate the severity of failures by markets, firms and governments, which in turn can result in permanent changes in the structure of the material market.

Table 1. Metrics Comparison

	Definition	Concern for firms
Malthusian	Measure of long term physical scarcity: a balance between how much is available and how fast it is being taken and processed.	Can indicate whether primary supply will accommodate sudden demand growths.
Ricardian	Measure of the level of quality of a resource and the effort required to obtain it.	Can indicate higher risks for cost increases.
Structure	Measures the geographic or market distribution of resources, production and consumption.	Can indicate market inefficiencies or supply chain instability.
Reclamation	Measures the proportion of secondary metal relative to primary metal consumption and availability.	Can indicate high dependance on foreign primary metal markets.
Price	Simply the market clearing price	Reacting post facto to increasing prices is a poor mode of managing risk

III. Platinum Metrics

For electronics manufacturers, PGMs are crucial to a number of applications, such as hard disks and capacitors. Small amounts are used, typically less than 1% by mass for cell phones [9], but high prices relative to other metals should make their scarcity an important consideration for manufacturers and recyclers alike [10].

In comparing metrics for different metals, PGMs are highlighted because of their low ore grades, the high energy costs for extraction, their high prices and the high concentration of production in a single country (see **Table 2**).

Table 2. Metal Metrics Comparison [3], [11], [12]

Metal	**Dynamic reserve - based depletion index (yrs)**	**Ore grade (wt %)**	**Energy (MJ/kg)**	**Price ($/t)**	**% primary produced in 1 country**
Magnesium	v. large	70-95% MgCO3, brine 3% Mg	257	2938	0.73
Aluminum	53	35-50% Al2O3	201	2391	0.35
Iron	96	30-65%	12	645	0.24
Lead	19	4-8%	21	3227	0.3
Zinc	18	2-4%	85	2881	0.24
Copper	20	0.2-5.0%	64	7773	0.37
Nickel	26	1.5%	195	30,748	0.23
Tin	16	0.5%	324	15,023	0.42
Cobalt	25	0.4%	132	65,725	0.31
Silver	11	0.006%	Not avail.	4.15×10^5	0.16
Platinum group metals	53	0.0003-0.002% PGM	196,000-846,000	1.45×10^7	0.75

A. *Malthusian: revolutionary demand*

Malthusian metrics are those that examine physical scarcity constraints by comparing how much of a resource is available to how much is being used. For a non-renewable resource, growth rates of consumption indicate how fast known resources are being consumed.

For platinum and palladium, automotive demand accounts for about half of total demand and is likely to have a greater impact on prices than electronics demand (see Fig. 1). Recent interest in developing a hydrogen economy based on fuel cell usage in the transportation industry have led to concerns for large demand growth.

In terms of platinum usage, each car presently uses about 5g, and a fuel cell car would use between 15 and 100 g [13]. Automotive applications are not the only ones where platinum is used for its catalytic properties. Approximately 2/3 of its demand results from its unique catalytic properties. With current technology, good substitutes in these applications are lacking. The best substitutes for platinum are other PGMs, which are mainly mined alongside platinum.

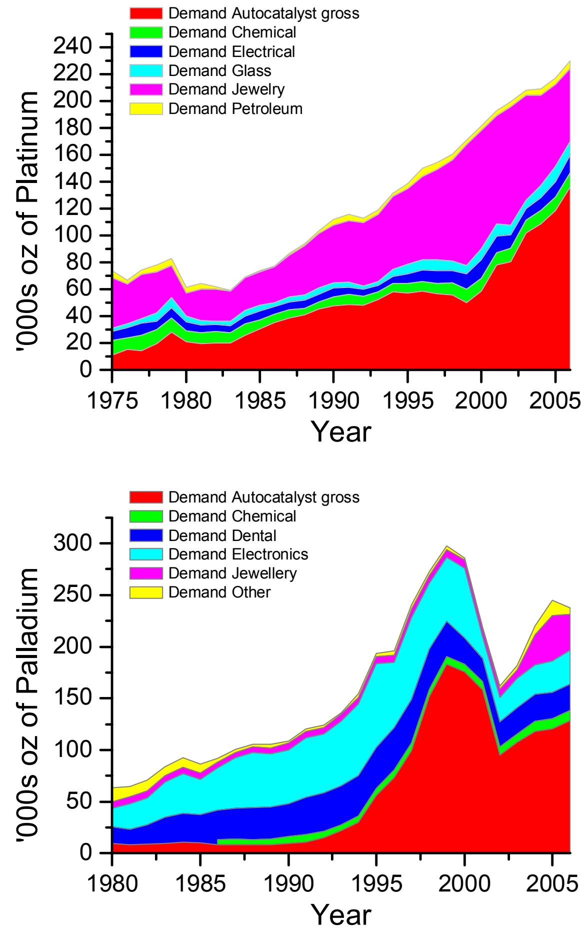

Fig. 1. Historic demand uses for platinum and palladium [14].

B. *Ricardian: ore grade and energy costs of extraction*

Ricardian metrics consider that physical constraints are determined by the effort required to obtain each kg of a metal, an effort that can be measured in monetary, energy or environmental units.

The costs of extracting platinum are much greater than those for many other metals, in part because of the low concentrations of platinum that can be found in ores. Platinum ore grade, a metric of physical scarcity, is typically 0.5 to 3 g/metric ton. This is 3 orders of magnitude lower than the average grade of copper, nickel, tin, zinc or lead. In the case of increasing energy costs or environmental regulations, platinum is more likely to experience large price increases than other metals.

Another factor to consider is the change of costs over time for extracting platinum. Mill head grade, an approximate measure for ore quality, is plotted for the four South African mines for which data was available in Fig. 2 [15]-[17]. Grades in these four mines have dropped with increasing amounts mined. Drops have also been observed for Stillwater mines in the US [18]. Costs for any individual mine increase with decreasing head grade. The decreasing head grade and increasing costs are expected to impact future supply costs and could also impact future scarcity.

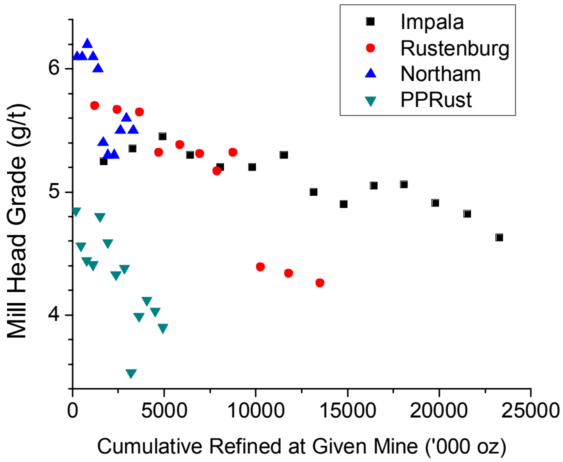

Fig. 2. Historic PGM mill head grades for four South African Mines. Data gathered from historic financial reports obtained from company websites [15]-[17]. Data spans from 1993-2006 for Impala, from 1997 to 2006 for Rustenburg, from 1996 to 2006 for Northam and from 1994 to 2006 for Potgietersrust.

C. Supply Structure and Reclamation: geographic and market distribution and recycling rate

Structure metrics, such as market distribution, indicate potential for institutional inefficiency. In the case of platinum, primary supply is concentrated in a single country, South Africa (75% of production, 88% of reserve base)[12]. Five companies (Lonmin, Anglo Platinum, Impala Platinum, Aquarius and Norilsk) control most of the primary supply [19].

The high concentration of PGM supply from South Africa means that any disruptions or uncertainty in that country could affect 75% of global platinum supply. South Africa's recent power supply shortage, which is expected to last up to 6 months, is an example of a common-cause failure. As a result of the power shortage, all South African mines have had to reduce production until the power shortages are alleviated [20].

Recycled (secondary) PGMs provide an alternative to primary supply. The secondary metal supply chain functions differently from the primary supply in a number of ways. First, secondary metals are collected from countries with high rates of consumption, typically, industrialized countries, and thus represent a domestic supply for these countries. Secondly, the supply of secondary metals cannot exceed the amount of metal in products reaching their end-of-life phase. Thirdly, the costs for recycling are generally lower than the costs for extracting primary [21]. Finally, the delays involved for recycling are different from those for mining primary because the infrastructure for recycling is different from that of the primary market.

Global recycling data was not found, but in a study of Germany's PGM materials flows, it was established that 45% of gross PGM demand was met by recycling [19]. Such high recycling rates mitigate the concern for the high primary supply concentration and also reduce the fraction of primary resources consumed annually, a Malthusian metric.

IV. Modeling Methods

A generic simulation model will be the experimental platform for examining the dynamics of metal markets that could lead to scarcity. Demand growth and supply structure, including recycling, which are issues of importance for platinum, will be the focus of the simulations.

The dynamic market model considers three questions: how supply varies with price, how demand varies with price, and how price varies with imbalances between supply and demand (see Fig. 3.). Primary supply is constrained by resource discovery and development, whereas recycled supply is constrained by end-of-life product disposal amounts.

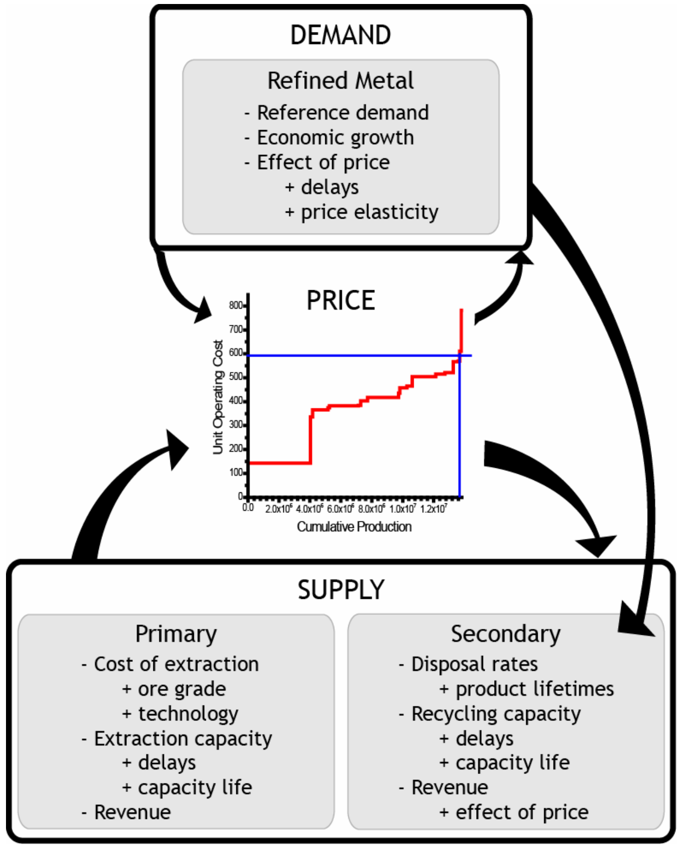

Fig. 3. Model structure diagram.

Supply, demand and price are determined endogenously in the model. Changes in price occur when there are imbalances between supply and demand. The supply curve is represented as the aggregated supply from multiple suppliers, each willing to offer a set quantity of the material at a given price [22]. Supply increases with increasing price, but can also change when changes occur to one or more of the suppliers. The demand curve is also made up of numerous actors; the manufacturers of consumer goods or parts for consumer goods are those who directly demand materials. Each of these stakeholders is willing to buy a certain amount of material at a given price. Demand decreases with increasing price for all elastic products but can also change as a result of economic and technological conditions.

Supply and demand depend on a number of exogenous variables. Exogenous variables that determine primary supply are the rates of change of ore grade and technology, the delays involved in adjusting the production capacity, and the desired rate of returns (cash flows). Exogenous variables that determine secondary supply are product lifetimes, delays for changing recycling capacity, and the sensitivity of collection rates to price.

For this paper, the generic model assumes that all primary suppliers perform equivalently. Demand is subdivided into four sectors: jewelry, automotive, electrical and industrial. Where possible, the model uses average platinum industry data such as average mill head grade, average operating costs, demand, and price elasticity. However, the model has not yet been calibrated and therefore the results provided are qualitative not quantitative. The model uses established system dynamics building blocks for a commodity market with a supply chain and product aging chains [23].

V. Modeling Results

A number of cases comparing demand growth, delays in acquiring primary capacity and recycling were run on the generic material market model with Run B defined as the base case.

TABLE 3. BASE CASE CONDITIONS.

Growth of underlying utility demand	Slow
Primary supply response delays	Medium
Recycling	Yes
Exogenous supply shortage event	None

A. Demand and supply capacity

Supply and demand vary with price, but respond only after a delay. The delay for a response in supply capacity to demand changes depends on the ability of mining companies and secondary suppliers to expand capacity. Primary manufacturing is capital intensive and generally has long delays. In the case of recycling, when prices are high, collection rates increase. Once products are collected, the recycling process can be very different. For example, with jewelry, recycling involves a simple remelting process. Recycling of automotive catalyst on the other hand involves smelting.

Delays for demand to respond to price vary depending on the ability of manufacturers to substitute for other metals. This can be straightforward (as with white gold substituting for platinum jewelry) or may require developing new materials or technologies.

Demand does not only vary with price, but also varies with external conditions such as regulations, industrialization and technological development. For example, increasing wealth and growing populations result in a need for more cars even if the price of cars does not change. The model takes such changes into account by defining an underlying utility demand (UUD) which allows for an exogenous growth of demand for a given platinum utility (ex: catalyst application). Demand can actually decrease with increasing UUD if price increases significantly and enough time is given to manufacturers to find a substitute.

The model was run with three different UUD growth conditions: none, low and high growth. If supply is unable to grow at the same rate as demand, prices increase. Increasing prices trigger investment in new primary production capacity and alternative materials.

The results for demand growth and price for a 50 year model run are shown in Fig. 4. We observe that the growth of UUD results in cyclical behavior. This behavior is explained by the delays involved for supply to increase in response to increasing demand. At first there is a material shortage which results in a price increase until supply catches up to demand and prices decrease.

Growth rates of UUD affect the amplitude of the market price cycle. The larger the growth rates of UUD, the greater the amplitude of the price cycle. All three runs (A, B, C) had the same delays for primary supply capacity and also have the same phase in the market price cycles. The role of the delays is further examined in Fig. 5, which shows runs B, D, and E. Larger delays result in a larger phase and amplitude of the price cycle

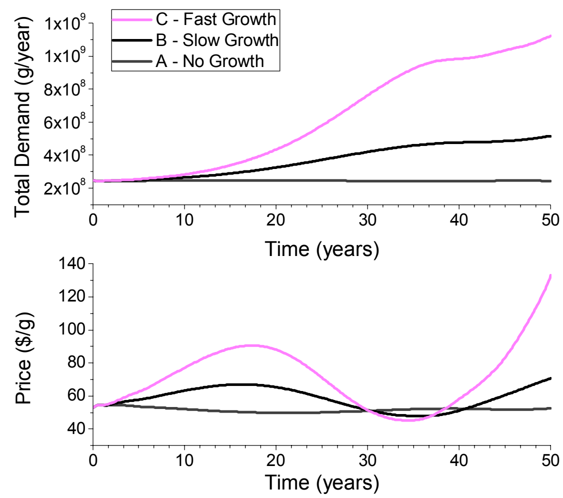

Fig. 4: Behavior of generic model with three UUD (underlying utility demand) growth conditions, medium delays and recycling.

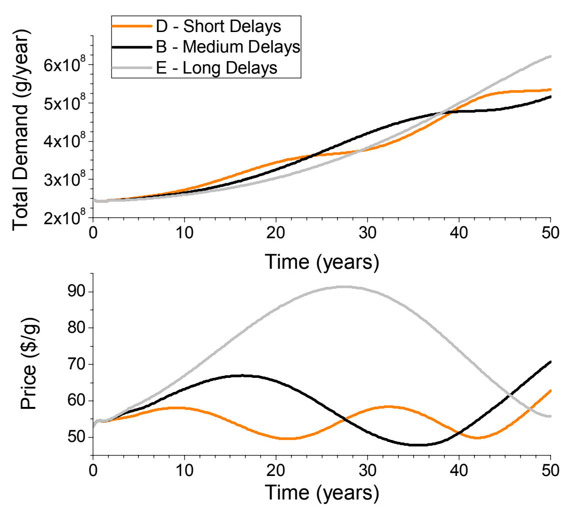

Fig. 5. Behavior of generic model with three primary supply delay conditions, slow UUD growth and recycling.

B. Secondary and primary supply structures

For this generic model, the different primary suppliers were modeled as having equivalent performance. The secondary suppliers were modeled differently from the primary suppliers. Having separate suppliers is considered a strategy for improving supply chain resilience [24] and it is proposed that having both secondary and primary suppliers improves material availability.

The impact of recycling is examined by comparing two cases with slow UUD growth, one with and one without recycling. In both cases, an additional scenario is run where there is a supply interruption of 50% of demand from year 17 to 18. Price and recycling rate are plotted for runs B and F in Fig. 6. Price and mining capacity are plotted for runs G and H in Fig. 7. In these runs, secondary material from the recycling process is assumed to be sold at the same price as primary material. This assumption is made for PGMs because for most PGM recycling processes, the product of the recycling process is of the same purity and quality as primary material.

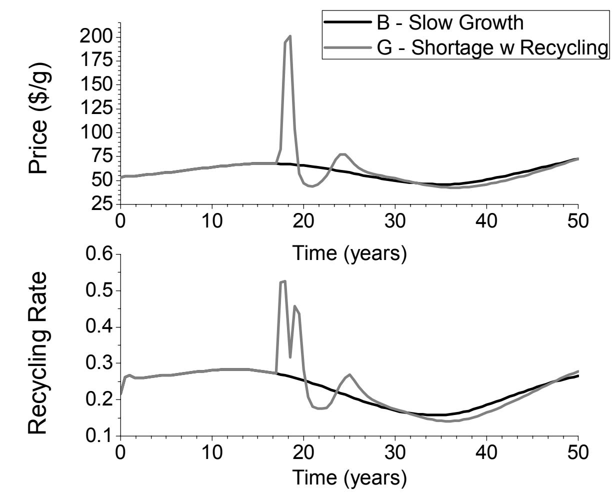

Fig. 6. Price and Recycling for the base case and the run with a one year supply cut. In both runs there is slow growth, medium delays & recycling.

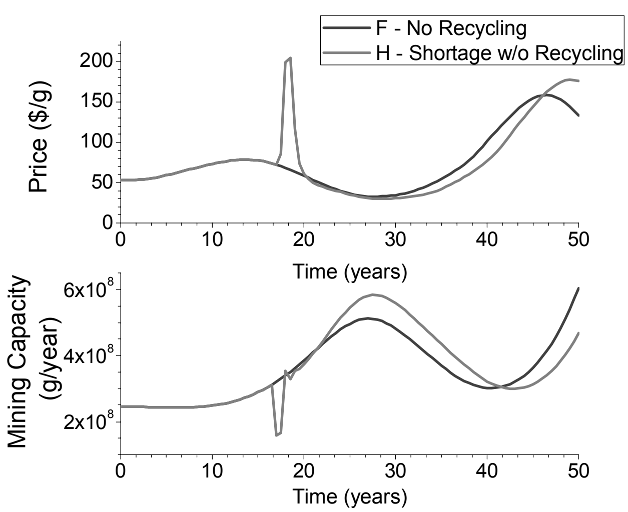

Fig. 7. Price and mining capacity with and without a one year supply shortage. In both cases, no recycling, slow growth, medium delays.

In Fig. 6, the result of the supply shortage is an immediate and significant increase of price. The price excursion leads to price fluctuations for a number of years following the initial excursion. Some of the supply shortage is offset partially by an increase in recycling. The increased recycling occurs because the higher price motivates increased secondary collection. However, the potential for increasing recycling is limited by the amount of products that can be collected after reaching end-of-life.

In Fig. 7, the price of run F is plotted and has greater fluctuations than run B, the base case plotted in Fig. 6 (variances of price in **TABLE 4**). The fluctuations occur slowly, giving firms in the model time to alter their demand for platinum and substitute for alternative materials or technologies. In the real world, this may not always be the case; alternative materials may not be developed soon enough to allow firms to reduce demand of an increasingly expensive material.

Recycling also results in decreased primary metal consumption. In the case of platinum, present reserves are very large and therefore degradation of the ore quality is not significant over the 50 year period under this slow demand growth scenario.

However, recycling does not significantly diminish the price excursion when comparing the price curves for runs G and H (**TABLE 4**).

VI. DISCUSSION

The generic model is a very simplified model of a material market where multiple actors participate on both the supply-side and demand-side. The model has not been validated to historical data but can be and is being used to examine the impact of a number of important factors on price and demand.

Ultimately, risk for scarcity needs to be quantified for downstream firms. In the first sections of this paper, metrics were proposed to compare the risk of scarcity occurring for different materials. Yet another set of metrics are required for evaluating the impacts of material scarcity on downstream firms. As a first step, the average weighted spending on the metal of interest and the variance of price and maximum price will be used to compare the different runs (see **TABLE 4**). The average spending is defined as:

Average spending =cumulative spending / cumulative demand

Fast demand growth, long delays for acquiring primary supply capacity and a lack of recycling are three conditions that result in greater material costs for downstream firms and are therefore less desireable. These three conditions result in the largest supply-demand imbalances.

Although supply shortages led to large initial price excursions followed by continued price fluctuations, the costs to downstream firms by the end of the 50 year period were essentially the same as the scenarios without supply shortages. The average spending was plotted over the 50 year period for the cases with recycling (runs B and G shown in Fig. 8). The average spending increases as a result of a supply shortage, but if the firm is able to continue through the shortage and subsequent years, the costs accumulated during the shortage are recovered. Recovery after a period of shortage also occurs in the case with no recycling.

TABLE 4. MEASURES OF EFFECT OF PRICE AND DEMAND TO DOWNSTREAM FIRMS.

	Maximum Price ($/g)	Standard Deviation of Price	Average Spending ($/g)
A - no growth	54.6	1.299	51.7
B - base case	72.6	7.401	57.6
C - fast growth	134.0	19.785	70.3
D - short delays	62.9	3.119	54.4
E - long delays	92.4	13.053	74.0
F - no recycling	158.4	37.067	73.9
G - supply cut w recycling	235.5	21.909	57.8
H – supply cut w/o recycling	238.3	43.650	70.2

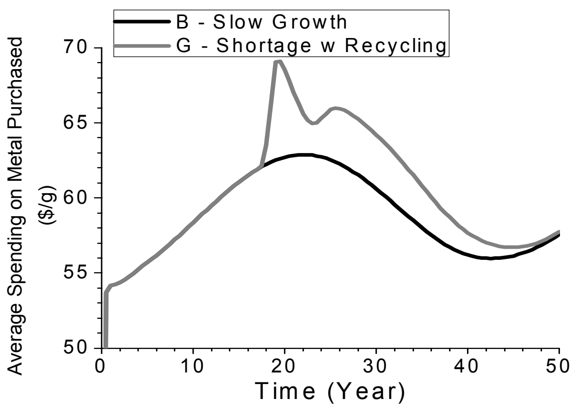

Fig. 8. Effect for downstream firms measured by average spending.

VII. FUTURE WORK

The goal in building a simulation model has been to obtain an experimental platform to study market behavior in the face of scarcity. In particular, under what circumstances might some metrics be more appropriate than others and what strategies are most effective to reduce the risk of scarcity for downstream firms?

Metrics have been defined to identify materials with a higher risk for future materials scarcity. Metrics are also required for determining the impact to firms of a given scarcity scenario. In this paper, the average spending metric has been used. It measures how much, on average, firms have spent on each unit of platinum purchased over a given period. Additional metrics should be examined in the future.

Past case studies have suggested that firms can mitigate the risk of scarcity through product redesign, substitution, increased recycling and targeted efficiency improvements. Since these strategies should be considered before such surges occur due to the implementation delays involved, a simulation model would provide a platform for firms to examine the consequences of their implementation. The model described in this paper can be extended to be more specific for platinum so that the model results can be validated with historical platinum data.

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