Strategies to Address Risks of Platinum Scarcity for Supply Chain Downstream Firms

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Abstract— **Increased recycling, product redesign and substitution can improve firm resilience in the face of uncertainties in materials availability. The delays involved in implementing these strategies may result in unprepared firms losing market share to competitors who are better prepared to address these challenges. This paper will expand from previous work in this area by examining the statistical significance of the effect of recycling in the face of limited supply. It has been shown that the timing and magnitude of a supply shutdown can influence the magnitude of price response. On average, increased recycling is a means for stabilizing price effects owing to its faster response times.**

Index Terms— **material scarcity, supply chain risks, recycling, platinum.**

I. INTRODUCTION

MATERIALS scarcity is an issue of concern. For an economy, materials are a key input for growth and development. For the environment, materials extraction and processing impact air, water and land quality. However, global concerns for scarcity do not necessarily translate to private actions, especially when some of the costs of materials usage are external to the market.

These general concerns do not necessarily translate into risks that motivate manufacturers. Risk of scarcity however should not be disregarded: scarcity can negatively impact firms through price surges [1]. During the cobalt supply disruptions in the 1970s, increased costs to private firms led to recycling, substitution, stockpiling and reduced material usage in a number of industries. These responses, taken by some firms, effectively changed the demand patterns for cobalt for years after the crisis had ended.

Recycling is the focus of this case study of the platinum market although there are other strategies worth examining

such as materials substitution and stockpiling, Recycling is considered as a scarcity risk-reducing strategy for manufacturing industries, in particular those that use platinum group metals (PGMs: platinum, palladium, rhodium, iridium and ruthenium).

Several aspects of the platinum market pose the risk of unexpected future increases in scarcity, making it a good case study. First, there is the risk for market inefficiency arising as a consequence of a high concentration of platinum supply, when measured both on a corporate and geographic basis. Five companies (Anglo Platinum, Norilsk Nickel, Implats, Lonmin and Inco) control most of the supply [2]. Primary supply of platinum is concentrated in South Africa (75% of production, 88% of reserve base) [3]. Second, there is also the risk that the cost of extracting platinum is more responsive to energy price increases than the cost for most other metals because typical platinum ore grades are 3 orders of magnitude lower than those of copper, nickel, tin, zinc or lead [4].

II. MODELING METHODS

In this research, the platinum market is modeled with a system dynamics simulation: a system of interdependent non-linear first order differential equations. The model simulates the behavior of key material market actors to explore the impacts of changing conditions on material scarcity over a 50-year time period. Although, market forces, especially price, balance supply and demand, the actions of suppliers, consumers, and market-makers can lead to unexpected market behavior, which frequently arise from imperfect information or poor understanding of the appropriate strategies.

A materials market is a complex system subject to dynamic feedback mechanisms that influence price, supply and demand over time. Systems with complex feedbacks have been studied previously using system dynamics [5-7]. The model described here uses established system dynamics building blocks for a commodity market with a supply chain and product-aging chains [8]. In this case, price, supply and demand are endogenously determined.

Fig. 1 is a model structure diagram that illustrates the key feedbacks between supply, demand and price, and the exogenous variables.

In the model, changes in price occur when there are imbalances between supply and demand. The supply curve is modeled by aggregating the supply from individual suppliers subdivided by region, each willing to offer a set quantity of material at a given price [9]. Supply increases with increasing

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price, with suppliers making decisions based on their cost structure and expected ability to profit. Gross demand is a sum of the demand from manufacturers of consumer goods or parts for consumer goods. Demand decreases with increasing price based on price elasticity. In addition, it is affected by exogenous economic conditions such as GDP.
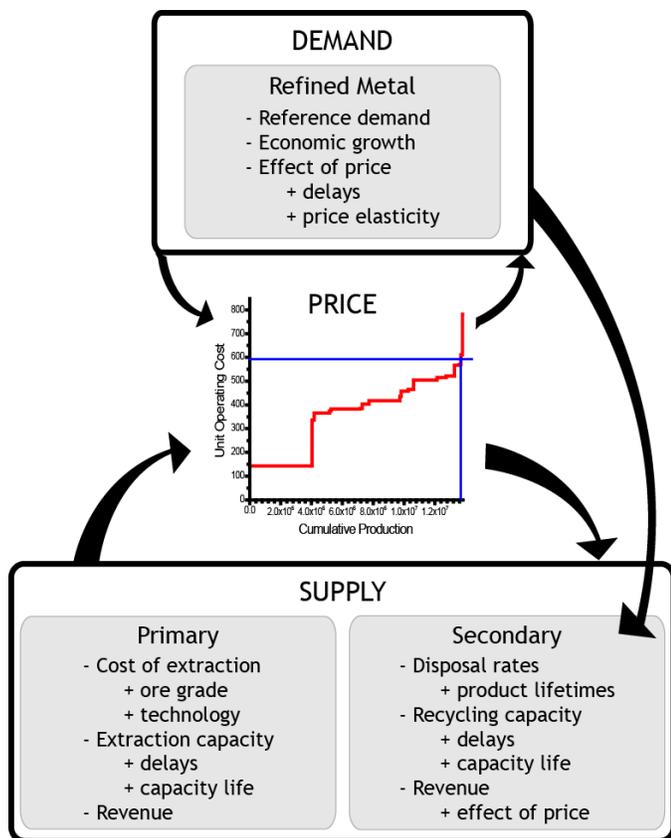

Fig. 1: Market model structure diagram with three sectors: Supply, Demand and Price. Curved arrows indicate information feedbacks; an increase in supply leads to a decrease in price following a delay, which then leads to a decrease in supply following another delay; similarly, increasing demand leads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

A. Structure Details

Material supply is the sum of primary (mined metal) and secondary (recycled metal) supply. The model assumes that secondary platinum is a perfect substitute for primary.

The model tracks primary platinum production by region and grade from discovery to extraction in order to estimate the expected costs of mining. When supply expansion is needed to meet growing demand, the model assigns a new mine to a region based on projected profit. Based on variable costs, the model determines each mine's capacity utilization, with utilization dropping to zero as prices fall below variable costs. Specifically, the primary supply curve at a point in time is calculated from the aggregated production data of eight major platinum-producing areas: (1) Merensky reef, (2) UG2 reef, (3) Platreef, (4) Great Dyke, (5) J-M reef, (6) Norilsk Nickel mines, (7) Sudbury mines, and (8) one greenfield region. Merensky, UG2 and Platreef are located in South Africa in the Bushveld complex and account for more than 70% of primary supply [10].

The model determines secondary supply by separately tracking end-of-life and collection rates for each platinum product category modeled: (1) jewelry, (2) vehicle catalysts, (3) electronics, (4) chemical catalysts, (5) petroleum, (6) glass, and (7) other.

The amount recycled depends on an expected average dynamic recycling rate and price. The dynamic recycling rate is the ratio of platinum that is recycled today over the amount of platinum that was put into use at the beginning of the product life. The high price of platinum relative to other metals is a strong incentive to recycle. Products have high dynamic recycling rates in cases where platinum is easy to recover (e.g., jewelry) or in *direct recycling* cases where collection is straightforward because the platinum is used at the manufacturing step rather than in the final product (e.g., glass and petroleum) [11]. Products have lower dynamic recycling rates in *indirect recycling*, where recycling requires complex extraction techniques and collection depends on consumers' returning the products (e.g., vehicle catalysts and electronics).

The model demand sector uses price elasticity and growth expectations for the seven platinum product categories listed above. Vehicle catalysts and jewelry account for most of primary platinum usage [12]. Investment demand has historically been small, but can have an important effect on the marginal price [13]. However, this demand category is not separately considered in the present model. Since some of the historic price behavior in the platinum market has been affected by investor demand, future work will need to incorporate this demand category into the model.

B. Partial model calibration using time-series data

The model uses platinum supply & demand data and material market behavior information to simulate the dynamic behavior of platinum supply, demand and price. Primary costs and capacity are estimated using resource data, such as the rates of change of ore grade and technology, the relationship between grade and cost, delays in adjusting production capacity, and the desired rates of return (cash flows) [12-20]. Secondary platinum supply data used by the model include product lifetimes, delays in recycling capacity changes, and the sensitivity of collection and recycling rates to price [11-13]. The demand data input into the model include initial platinum use rates and the delays and elasticity of demand in response to price changes [12, 21].

Two sources of time series data were used for partial model calibration [12, 13] — comparing model behavior with historic time series data and identifying parameters values that produced the best results. Price, supply and demand sector were calibrated separately and then combined in a single simulation for comparison with historical behavior. The process was iterative: the calibration would result in decisions to change model structure and the model would then be recalibrated and reanalyzed.

C. Modeling conditions

The base case conditions for the model are:

- 50-year time frame, with 1/32nd year simulation time steps
- 8 primary supply groups (mining regions)
- 7 demand groups (jewelry, vehicle catalyst, electronics, chemical catalyst, petroleum, glass, other)
- 7 recycling supply groups (same categories as for demand groups)
- product demand growth follows historical (1975 to 2008) trends and also depend on modeled price
- initial primary demand based on 1985 demand: 90 t/year,
- initial base case recycling rate:
  - *dynamic recycling rate* = secondary use/platinum in products reaching end-of-life = 67% ,
  - *static recycling rate* = secondary use/total use of platinum = 42%

Four other scenarios, which are variations on the base case, are outlined in TABLE I.

TABLE I: DESCRIPTION OF CONDITIONS FOR SIMULATION SCENARIOS.

Scenario	Recycling	Perturbation
A	Base	None
B	25% of base	None
C	Base	1 year, 50% of primary supply shutdown
D	25% of base	1 year, 50% of primary supply shutdown
E	Unresponsive to price	1 year, 50% of primary supply shutdown

Model sensitivity to parameters was assessed. The main results that will be discussed here include sensitivity tests on dynamic recycling rate (Case B) and timing of a supply-side perturbation (Cases C, D, E). The parameters were varied with a random distribution and 200 sample points were taken.

III. MODELING RESULTS AND DISCUSSION

The model is not designed as a forecasting tool; rather the intent of its design is to develop an experimental platform for exploring the dynamics of metal markets in the presence of scarcity risks. Although the model uses average platinum industry data, the scenarios explored are not historical. The following results are qualitative.

There are advantages to recycling that can be identified by examining the impacts of materials scarcity risks to private firms. These advantages may not all be considered by firms. The model is used to examine recycling advantages that can be system-wide and those that are industry specific. Due to the relatively high recycling rates of the base case platinum system, the model was used to assess the merits of the recycling strategy by decreasing rather than increasing the recycling rates from the base case.

A. System-wide benefits of recycling under well-behaved market scenario

Fig. 2 presents the price profile for two different cases where only the dynamic recycling rate was varied. In Case B there was a 75% cut in the recycling rate across all the industries; in other words, the dynamic recycling rate was 25% of the base case recycling rate. This figure yields two

main observations. First, the price trajectory in Case B shows greater variation than the price in Case A, the base case. Second, on average, over the 50-year period, the price in Case B is higher than in Case A. Further analysis of the impact of recycling rate was done through sensitivity analysis.
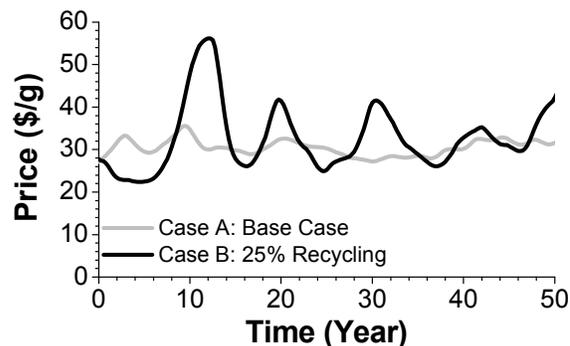

Fig. 2: Price profile over 50-year period with platinum market model for Case A: base case and Case B: Recycling cut by 75% from base case = 25% of base case recycling rate.

Dynamic recycling rate was varied from zero to the base case recycling rate of 67%. Sensitivity of the price to the recycling rates was tested for 200 randomly selected rates over this range. Average price and the standard deviation of price were plotted to show the trend as the base case recycling rate was cut (see Fig. 3). Both average price and the standard deviation of price increased as recycling rate decreased. However, while the average price increased by less than 35% over the range tested, the standard deviation increased almost 8-fold.

The increase in the price is partially related to increasing costs as a result of depletion: the demand and growth in demand for primary platinum is higher under the lower recycling scenarios. The increase is low because while primary platinum supply is currently limited to only a few source countries, the amount of known and economically viable resources (reserves) in these few countries is very large relative to the extraction rates over the past 30 years. Moreover, data from the major platinum producers indicate slow depletion rates of ore grade at present extraction rates. The quality of the reserves in some of the largest mines (Rustenburg and Impala) have not decreased significantly over the past 10 years and reserve grade estimates for many of the mines, including these large mines, are similar to presently mined grades. As a result, significant depletion of ore quality and the concomitant increases in extraction costs are not expected in the model's time frame, even without recycling. It is important to note here that the model begins at 1985 levels of primary demand. In the case of a metal with smaller reserves and a steeper expected ore degradation rate, the impact of recycling on average costs would be much larger.

On the other hand, the increased stability of price achieved through increased recycling is a consequence of the very different structures of the primary and secondary supply chains: the secondary supply structure responds more quickly than the primary supply structure and is constrained by product lifetime and past demand rates rather than by geological factors. While primary production capacity depends

on large mining operations that require huge capital investment and may need to overcome government regulation hurdles, recycling facilities vary from small-scale remelters to larger scale, multi-product recyclers. The model captures this difference mainly by imposing a longer delay for changing production capacity for primary suppliers than for secondary suppliers. The ability of recycling to stabilize price is a result of the ability of secondary suppliers to respond quickly to price. Increasing the time it takes for primary and secondary suppliers to respond to price also results in higher oscillations in price.
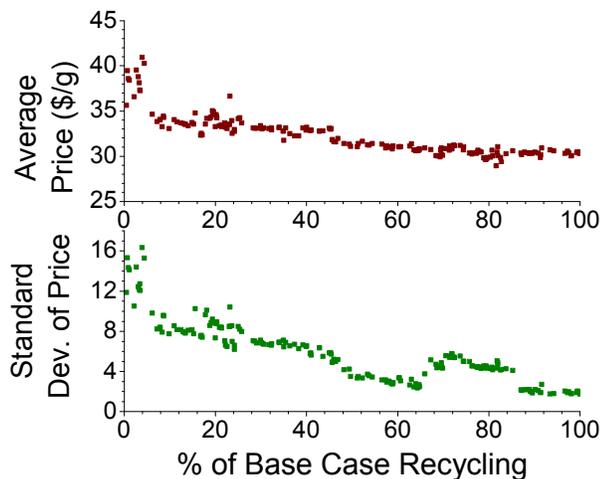

Fig. 3: Average price and standard deviation of price over 50-year period as recycling rate is varied from 0 to the base case value of 67%.

B. System-wide benefits of recycling under perturbed market scenario

While the preceding analysis assumed a well-behaved market with steady sources of supply and stable demand behavior, markets also can undergo abrupt perturbations, such as supply chain interruptions due to political or natural environmental events and emergence of new demand due to technological changes, etc. In the case of platinum, speculative demand (on the order of as much as 20% of total industrial demand) has also led to market perturbations.

To explore the effect of an abrupt market perturbation, a cut in primary supply from mines can be simulated under two recycling scenarios --- the base case recycling rate (Case C) and 25% of base case recycling (Case D). They are graphed in Figure 4 and Fig. 5. In order to compare Cases C and D, they are graphed together with Cases A and B, respectively.

In both scenarios, price increases as a result of the supply interruption and remains high for longer than the 1-year duration of the interruption. The perturbation does not appear to result in long term changes in the average behavior of price, although the path taken changes slightly.
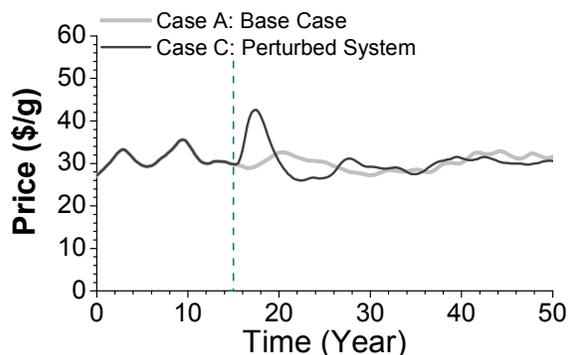

Fig. 4: Price as a function of time for Cases A & C: base case recycling without and with a perturbation. For illustration purposes, the case of a perturbation starting in year 15 is shown.
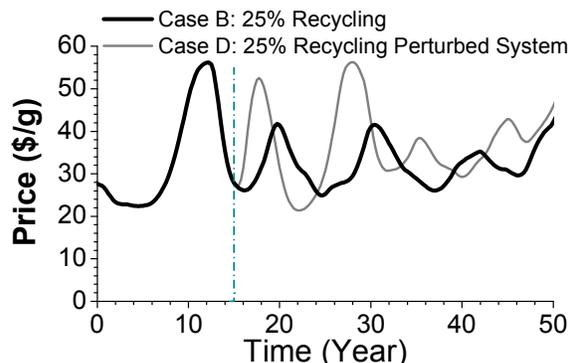

Fig. 5: Price as a function of time for Cases B & D: 25% recycling without and with a perturbation. For illustration purposes, the case of a perturbation starting in year 15 is shown.

The effect of such a perturbation was studied through sensitivity analysis, by varying the incidence of the perturbation between years 5 and 25. Three scenarios of recycling were examined: the base case recycling, a case where recycling was 25% of base case and a case where recycling was unresponsive to price changes (Cases C, D & E). The average price, maximum price and standard deviation of price over the 50-year period for each of the simulation runs were measured and then averaged (see TABLE II).

TABLE II: PRICE STATISTICS FOR WELL-BEHAVED MARKETS (CASES A, B) & FOR PERTURBED MARKETS (CASES C, D, E). THE PERTURBED MARKET RESULTS ARE AVERAGED FROM 200 SIMULATIONS VARYING THE TIME OF THE PRIMARY SUPPLY INTERRUPTION.

	Average Price ($/g)	Standard Dev. Price	Maximum Price ($/g)
A – Base	30.5	1.84	35.6
B – 25% recycling	32.6	7.77	56.2
C – Perturbation sensitivity, Base recycling	30.8	3.45	45.5
D – Perturbation sensitivity, 25% recycling	36.7	11.3	73.1
E – Perturbation sensitivity, recycling unresponsive to price	31.4	4.11	46.7

Limiting the amount recycled or making recycling rates unresponsive to market signals (price) increases the market's sensitivity to the price increase arising from the perturbation. As in the case of the unperturbed system, the key benefit of recycling is a reduction of the oscillations of price. Recycling stabilizes price not just by providing an alternative supply

source that is not affected by primary supply shutdown, but also by responding to price as highlighted with Case E.

C. Industry-specific benefits of well-established recycling infrastructure

Recycling is dependent upon the existence of an effective collection infrastructure. For most consumer products, such as vehicle catalysts, jewelry and electronics, the recycling rate of end-of-life products depends on consumer behavior, and low collection rates result in large losses of material [11]. In these indirect recycling systems, the immediate cost savings from recycling are captured by intermediate recyclers.

For direct recycling, the recycler and the manufacturer devise a contractual arrangement to manage the collection of platinum for recycling. Such types of contracts are often toll-refining contracts, wherein the recycler is paid to refine the collected platinum for reuse by the manufacturing plant that supplied it. Manufacturers that can establish direct recycling contracts benefit from the lower cost of refining secondary platinum relative to the cost of extracting and refining primary platinum. Moreover, direct recycling should also limit exposure to the risk of price fluctuations.

The model will be used to examine the dynamics of and the extent to which direct recycling reduces the impact of changes in platinum price upon a firm. Industry-level platinum expenditures and total platinum expenditures are measured and used here as metrics of the benefits of recycling infrastructure. Platinum expenditures are calculated as follows:

$$\frac{dE}{dt} = MP_t * P_t + TR * S_t \tag{1}$$

$$E_{unit} = \frac{\sum_{t=0}^{50} MP_t * P_t + TR * S_t}{P + S} \tag{2}$$

E = Total Expenditures over 50-year period ($)
E_{unit} = Weighted Average Industry Unit Expenditure over 50-year period ($/g)
MP = Market price of platinum at time, t ($/g)
P = Primary platinum purchased (g)
TR = Toll-refining charge ($/g)
S = Secondary platinum recycled for reuse (g)

Firms seek to minimize their expenditures given a desired production level. Moreover, expenditure uncertainty presents a risk to firms, especially when expenditures are above anticipated expenditures. To first order, manufacturers can base their estimates of future expenditures on past expenditures. In this analysis, firms are assumed to estimate future price based on a two-year moving average of past prices. The difference between actual and anticipated expenditures is measured at each point in time:

$$E_{unanticipated} = E_{actual} - E_{anticipated} \tag{3}$$

Unanticipated expenditures increase firm costs. A positive unanticipated expenditure means that more funds are required to purchase needed platinum, directly increasing firm costs. When unanticipated expenditures are negative (i.e. the actual

expenditures were lower than anticipated), the firm incurs an opportunity cost of the excess – essentially, it has held cash that should have been applied to other purposes. The relative cost of unanticipated expenditures is calculated as the sum of the cost from underestimating expenditures and the opportunity cost of capital from overestimating expenditures at each point in time.

$$C_{E_{unanticipated}} = C_{E_{underestimate}} + C_{Capital_{opportunity}} \tag{4}$$

$$C_{E_{underestimate}} = \text{positive values of } E_{unanticipated} / E_{anticipated}$$

$$C_{Capital_{opportunity}} = (ROR_{Capital} * \text{negative values of } E_{unanticipated}) / E_{anticipated}$$

$ROR_{Capital}$ = rate of return of capital

Expenditures are examined in the context of an industry that performs direct recycling: glass. Platinum use in the global glass industry has increased from 2 tonnes per year in 1975 to 13 tonnes per year in 2007, when it accounted for 6% of primary platinum demand [12]. Data was not available for global amounts recycled, but it has been estimated that 98% of platinum used for glass production in Germany is recycled through direct recycling [11]. If the German recycling rates apply to the global glass industry, the amount of platinum used in glass production is much greater than the value give in the preceding primary demand estimates.

Toll refining charges are estimated at 5% of primary platinum extraction costs, based on life cycle estimates that recycling of platinum uses 95% less energy than primary extraction (Simapro LCA data).

The model is used to calculate expenditures for cases A, B and C, and results are presented in TABLE III. Average unit expenditure is estimated for the glass industry with indirect recycling (savings from recycling not captured by glass manufacturers) and with direct recycling (savings captured by glass manufacturers). As expected, the expenditures for manufacturers that participate in direct recycling are much lower than those that do not. The benefits of having a direct recycling infrastructure are particularly large because the glass industry can recycle almost all of the platinum that it uses. Moreover, the incentives for direct recyclers to minimize the losses during the use phase are shown to be much higher. When recycling rates are cut by 75%, the glass industry unit expenditures under indirect recycling increase only slightly, but under direct recycling, the spending increase is almost five-fold. This result confirms that indirect recyclers, such as the automotive industry, do not have strong incentives to devise or promote effective recycling infrastructures.

The uncertainty under direct recycling is also smaller as measured by the average percentage difference between actual and anticipated expenditures. In Case A, actual expenditures are on average 2.88% different from the anticipated expenditures with direct recycling, while they are on average 3.63% different with indirect recycling. When recycling is cut by 75%, the difference between anticipated and actual expenditures increases because prices oscillate more (standard deviation of price for Case B is greater than for Case A as

shown in TABLE II), but the effect is especially pronounced in the case of indirect recycling. Case C also leads to a higher percentage difference between actual and anticipated expenditures than Case A, again due to the larger price oscillations resulting from the perturbation. In large part, firms that participate in direct recycling are protected from primary price uncertainty because of the relative stability of toll-refining charges and to decreased primary platinum use.

TABLE III: AVERAGE UNIT EXPENDITURE AND AVERAGE RELATIVE COST OF UNANTICIPATED EXPENDITURES FOR A GLASS INDUSTRY WITH INDIRECT RECYCLING AND WITH DIRECT RECYCLING.

	E_{unit}	Ave. Rel. Cost $E_{unanticipated}$	E_{unit}	Ave. Rel. Cost $E_{unanticipated}$
		(indirect)		(direct)
A – Base	30.2	3.63%	5.64	2.88%
B – 25% recycling	32.7	29.2%	25.9	5.52%
C – Perturbation sensitivity, Base recycling	30.2	5.55%	5.66	4.19%

IV. CONCLUSIONS AND FUTURE WORK

The ultimate goal of this research is to better quantify the risk of scarcity for downstream firms. Price and expenditure are two metrics that have been used to examine the benefits of recycling in a well-behaved market and in one where there is a single perturbation event. Depletion from scarcity of primary platinum resources is not of significant concern for the next few years. Still, recycling is beneficial under well-behaved market conditions because it can help stabilize the markets through more rapid price responses, resulting in more timely growth in material supplies. Recycling also stabilizes price in the case of a market perturbation. The variability of price increased more as a result of the perturbation when the recycling rates were cut.

The variability of platinum expenditure by downstream firms is a metric that was used to examine the impact of price on manufacturers. As expected, industries with direct recycling benefit from the lower costs of toll-refining relative to primary platinum. The model was used specifically to examine how direct recycling reduced firm-level expenditure uncertainty due to the relative stability of toll-refining charges compared to price. In the case of reduced recycling, which has a higher standard deviation of price over time, the average relative costs of unanticipated expenditures were five times higher with indirect recycling than with direct recycling.

Both scenarios studied here are unrealistic since markets generally experience many perturbations over time. However, the goal in building this simulation model has been to obtain an experimental platform to study market behavior in the face of scarcity. As such, the model has successfully been used to identify benefits for recycling that firms may not have considered: market price stability, and hence a decrease in the uncertainty of future expenditures.

Two other strategies were suggested at the beginning of this paper: materials substitution and reduced materials usage. The simulation model will be used in the future to examine how these strategies perform compared to recycling. Additional metrics should be proposed and evaluated to identify the benefits of these alternative strategies.

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