Cash Settlement or Physical Settlement? Determining the Optimal Mechanism for a Futures Contract on Recycled Plastic

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ABSTRACT New market mechanisms aiming to apply the tools of finance for addressing environmental challenges have emerged in recent decades, such as debt-for-nature swaps, voluntary carbon markets, and conservation trust funds. One market mechanism which has not received as much attention has been the futures contract. This case study and a companion case in this same journal examine the potential of exchange-traded futures contracts to address inefficiencies in the recycling market. While the companion study examines the rationale for such a market, and barriers facing its operations, this case study explores a vitally important technical detail of a futures market for recycled material: mode of settlement. Here, we evaluate cash and physical settlement mechanisms and consider their implications for market participation, logistical complexity, and meeting regulatory requirements. The case study focuses on the Plastic Recycling Corporation of California (PRCC) and its Grade A PET (polyethylene terephthalate) plastic market. Data from PRCC auctions (2014–2023) reveal the viability of Grade A PET as an initial test case for standardized futures contracts, given its consistent trading activity and price trends. The study emphasizes the transformative potential of these financial innovations to incentivize sustainable practices, support manufacturing commitments to recycled content, and improve overall recycling efficiency. By integrating financial instruments like futures contracts, the study explores pathways to enhance price transparency, reduce market volatility, and align supply with demand in postconsumer materials. **KEYWORDS** sustainability, environment, recycling, futures contracts, cash settlement, physical settlement

CASE CONTEXT

Market mechanisms offer a powerful set of tools to align environmental protection with economic incentives. Traditionally, environmental challenges have been addressed through command-and-control regulations that restrict pollution levels or require specific practices. While these approaches can be effective, they often lack flexibility and impose uniform requirements regardless of context. In parallel, financing for environmental conservation and remediation has focused on grants from charitable organizations or government entities. Again, these pools of funding can lead to effective outcomes but are inherently limited in scope.

Market mechanisms, in contrast, leverage price signals and voluntary exchanges to incentivize environmental stewardship. By assigning economic value to ecosystem services and environmental externalities, these tools can engage private sector actors and unlock large-scale investment in conservation. For instance, payments for ecosystem services provide direct financial incentives to landowners and communities who manage their land in ways that support ecosystem functions like clean water, carbon sequestration, or habitat preservation. Other market mechanisms include financial instruments such as green bonds, blue bonds, conservation trust funds, and impact investment vehicles. These tools help direct capital toward long-term environmental projects by offering investors returns tied to measurable sustainability outcomes. Blended finance approaches—where public or philanthropic capital de-risks private investment—are increasingly common in global conservation efforts. Examples include debt-for-nature swaps, biodiversity credit markets, and pay-for-success models, which link repayment to verified conservation impact. These mechanisms allow environmental goals to be pursued not just as moral imperatives but as economically viable ventures.

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Market mechanisms for addressing environmental challenges can also be identified at the most abstract and innovative edges of finance. For instance, emissions trading systems, such as carbon markets, cap the total allowable level of pollution and allocate or auction tradable permits to emitters. Companies that reduce emissions can sell unused permits, rewarding innovation and cost-effective reductions. A parallel model—biodiversity offsetting—creates tradable credits for measurable biodiversity improvements, which can be used to compensate for unavoidable environmental damage elsewhere. Other structures focus on tradable rights, such as development rights or water withdrawal rights. Tradable rights mechanisms are a key category of market-based environmental tools that allocate rights to use or develop natural resources, which can then be bought, sold, or transferred among stakeholders. These systems aim to redirect development or resources away from ecologically sensitive areas by creating financial incentives for conservation. One of the clearest illustrations of this in practice is the Pinelands Development Credit Program in New Jersey (see Howell et al. 2022).

Market mechanisms aimed at reducing carbon emissions and achieving other environmental objectives can affect developed countries in a variety of ways. They incentivize companies to reduce emissions by investing in cleaner technologies and practices within their operation or by purchasing allowances from more efficient firms. However, this environmental improvement could be accompanied by higher production costs, leading to inflation or unemployment. Developed countries that implement pro-environmental policies risk becoming less competitive than developing countries that don't implement these policies. This suggests a coordinated approach between developed and developing countries to address environmental challenges. For example, Carbon Border Adjustment Mechanisms would impose a fee on goods and services imported from countries with less rigorous carbon pricing mechanisms.

Environmental issues are a global concern, but the approaches to address these concerns may differ between developed and developing nations due to differences in socioeconomic conditions and capacity for implementation. Developed countries must lead the transition to a circular economy by supporting businesses that adopt circular models and by investing in clean energy technologies. Developed countries must make these new technologies accessible to developing countries and subsidize the implementation of these technologies in developing markets. On the other hand, developing countries need to address some of the root causes of environmental challenges such as poverty and income inequality. Developing countries need to implement those cleaner technologies shared by developed countries. Finally, developing countries need to engage local communities about the importance of environmental decision-making since these communities focus on economic growth above all else. All countries must work together to support and enhance international agreements and initiatives that support environmental issues, such as the Paris Agreement and the United Nations Sustainable Development Goals.

Our research examines the potential application of traditional, exchange-traded financial derivatives, like futures and options contracts, to improve efficiency in the recycling industry. A 2021 *Wall Street Journal* article summarizes the main problem with the modern recycling industry (Ryan 2021). There is high demand for recycled materials, driven by large multinational corporations who pledge to improve sustainability by increasing consumption of recycled materials. However, potential corporate buyers struggle to satisfy these pledges because of decentralized markets and uncertain prices of recycled materials. The 2021 U.S. Environmental Protection Agency (USEPA) National Recycling Strategy lists as its top priority to "improve markets for recycled commodities through market development, analysis, manufacturing, and research" (USEPA 2021).

We advocate for the listing and trading of exchange-traded futures contracts on recycled plastic and other recycled materials. In a futures contract, two parties agree to exchange a specified quantity of an underlying asset for a specific price on a specified expiration date. The futures contract transaction locks in a future purchase price for the buyer and locks in a future sale price for the seller. For example, a corn farmer would be a natural seller of corn futures, and the Frito-Lay corporation would be a natural buyer of corn futures. In this example, both the buyer and seller protect themselves from adverse price changes. Buyers or sellers can close out their positions at any time and realize any gains or losses that result from changes in the underlying asset price, or they can roll over their positions to the contract with the next expiration date if they wish to maintain the same price-risk exposure to the underlying asset.

Exchange-traded derivatives have long been understood primarily as a mechanism to manage the risk associated with changing prices. However, research has also demonstrated that futures and options trading, particularly in the realm of commodities like agricultural and mineral products, makes extensive impacts on the natural environment. Cronon's (1991) book, *Nature's Metropolis: Chicago and the Great West* examines how financial instruments—particularly derivatives—helped reshape the physical environment. In the case of grain, for example, the development of standardized grading systems in Chicago's Board of Trade decoupled commodities from their physical origin. Grain became tradable not as bags of wheat from specific farms, but as bushels of Grade No. 2 wheat, interchangeable with others of the same quality. This abstraction made it possible to trade grain futures (contracts for future delivery of standardized commodities) without handling the physical product. This financial abstraction had practical ecological and social consequences: for instance, the desire for consistent, high-quality grain led to the spread of monocultures, the standardization of agricultural practices, and the expansion of railroads and storage systems to support the new market logic. Futures trading did not just manage risk—it actively shaped landscapes, influencing what was planted, where, and how. Similarly, the commodification of meat, timber, and other resources through Chicago's markets encouraged resource extraction and landscape transformation at unprecedented scales.

In this example, it is easy to understand how something like a futures contract for corn, beef cattle, lumber, or natural gas could expand the production of those commodities. For these reasons, futures contracts have conventionally been understood as mechanisms which encourage additional resource extraction. However, we propose to introduce futures contracts for products that would lead to environmental benefits. Our earlier research has focused on establishing futures contracts for postconsumer recycled materials with the goal of expanding the use of these commodities. Moore, Folkinshteyn, and Howell (2022) show that the price volatility of recycled materials is higher than the price volatility of identical new materials. Moore, Folkinshteyn, and Howell (2022) also review a substantial academic literature and find that the introduction of exchange-traded derivatives improves the underlying market quality of the underlying asset across a wide range of assets, including individual stocks, stock indices, commodities, and cryptocurrencies (Conrad 1989; Bansal, Pruitt, and John Wei 1989; Bessembinder and Seguin 1992; Antoniou and Holmes 1995; Kumar, Sarin, and Shastri 1998; Hegde and McDermott 2004; Kochling, Muller, and Posch 2019). These findings suggest that the introduction of exchange-traded futures on recycled materials would reduce the price volatility of recycled materials due to the hedging activity of market participants. In a companion case published in this journal (Howell and Moore, forthcoming), we examine the practical barriers to implementing futures contracts on recycled material based on extensive interviews with potential market participants.

In this case study, we explore an extremely important technical detail of a futures market for recycled material: mode of settlement. We evaluate cash and physical settlement mechanisms and consider their implications for market participation, logistical complexity, and meeting regulatory requirements. The question of how to settle transactions on a derivatives exchange is vitally important. Some derivatives trade with physical settlement, meaning the commodity involved literally changes hands between parties, for a previously agreed upon price on a predetermined date. Others trade with cash settlement, meaning that buyers and sellers simply exchange the profit and loss in cash from the difference between their agreed price at the time of trade and an established "index price" on a predetermined settlement date. This case study examines trading activity by the Plastic Recycling Corporation of California (PRCC), an organization that links buyers and sellers of recycled plastic. The PRCC has operated biweekly auctions on recycled plastic since 2014. Ultimately, our objective is to determine whether futures contracts on California recycled plastic should be listed with cash settlement or physical settlement. While listing exchange-traded futures contracts has the potential to increase recycling efficiency regardless of the mode of settlement, determining the specifications of the futures contracts that will generate the most trading activity is critical to maximizing, not just increasing, the efficiency and environmental benefits of the recycling industry.

CASE METHODS

Futures contracts could be created on any specific type of recycled material: glass, aluminum, cardboard, or plastic, as well as the various grades and subtypes of those materials. Each of those contracts would have different specifications and trading characteristics. In this study, we have chosen to focus on a single type of material, Grade A PET (polyethylene terephthalate) plastic. Grade A PET is a clear plastic of the type commonly used in water or soda bottles. Within markets for recycled materials, Grade A PET is considered ideal for recycling—it can typically be recycled back into food-grade packaging, like new beverage bottles, or spun into high-quality fibers for clothing and textiles.

We focus on the "PRCC" and its Grade A PET plastic market. The PRCC has held auctions to match buyers and sellers in four different grades of recycled plastic. Data from PRCC auctions from 2014 to 2023 reveal a consistent increase in demand over time for Grade A PET relative to the other three grades of recycled plastic, suggesting the viability of Grade A PET as the most promising initial test case for standardized futures contracts. With this background, we will propose a series of questions about whether such a contract should utilize cash settlement or physical settlement. We will also examine other important mechanical issues, such as the appropriate contract size and frequency of settlement.

CASE EXAMINATION

The PRCC emerged in June 1987 as a key component of California's Beverage Container Recycling and Litter Reduction Act. Initially focused on carbonated beverage containers, the organization's scope expanded in 2000 to encompass nearly all beverage containers, driven by collaborative efforts with the soft drink bottle manufacturing industry. As a nonprofit dedicated to environmental sustainability, PRCC plays a critical role in the PET recycling ecosystem. The organization's core mission centers on increasing recycling rates, ensuring stringent quality control, and developing stable markets for recycled materials. The PRCC accomplishes this goal by purchasing PET bottles from collection services and reselling them to reclaimers across the United States and internationally. In this way, PRCC creates a robust recycling supply chain that benefits both environmental goals and economic interests. In 2021, the organization processed an impressive 230 million pounds of PET, and these materials were transformed into diverse products including new bottles, food containers, carpeting, clothing fibers, and industrial strapping. Under the leadership of President Patricia Moore and Executive Director Sally Houghton of Sustainable Materials Management of California, PRCC continues to drive innovation in waste reduction and material reuse.

The PRCC operates an auction marketplace for bales of four different grades of recycled plastic. PET A includes more than 95% of PET beverage bottles and up to 5% of other PET containers. PET B includes 85% of PET beverage bottles and up to 15% of other PET containers. PET B with thermoform includes an average of 18% thermoform (non-bottle plastic packaging such as egg cartons). The PRCC also sells bales of thermoform isolated from any bottle packaging. The PRCC solicits prices from an extensive network of potential buyers and sellers of the four material types and holds an auction every 2 weeks.

PET A plastic is typically used for high-quality applications like water bottles, food containers, clothing, carpeting, and food containers. Grade A PET would be favored for "closed-loop" recycling applications, like recycling used plastic water bottles into new plastic water bottles. Grade B PET is often used for lower-quality products or when recycled content is acceptable, such as in some textiles, packaging, and construction materials. Since PET A is typically higher purity and free from contaminants, while PET A may contain a mix of colors and other imperfections, it is costly to upgrade PET B to PET A. There are two primary strategies to upgrade the quality of recycled plastic: using advanced mechanical techniques such as spectroscopy and using complex chemical processes such as depolymerization or solvent dissolution.

We expect to observe a higher demand for PET A than PET B because PET A is required for some critical recycling applications and it is expensive and complicated to convert PET B to PET A. In our analysis, we show that in the last decade, demand for PET A has increased relative to PET B and therefore PET A would be the ideal underlying commodity for a futures contract on recycled plastic.

Figure 1 shows the trend in trading volume for PET A and PET B over time. The figure indicates that buyers and sellers have consistently traded significantly more bales of PET A than PET B. While both materials have experienced fluctuations, the overall trend suggests a gradual increase in the total volume of PET A and PET B processed over the years, with a notable spike in 2021 and 2022. Figure 2 shows the price trend over time for the two PET types. The figure reveals that the prices of both PET A and PET B have been volatile, with significant

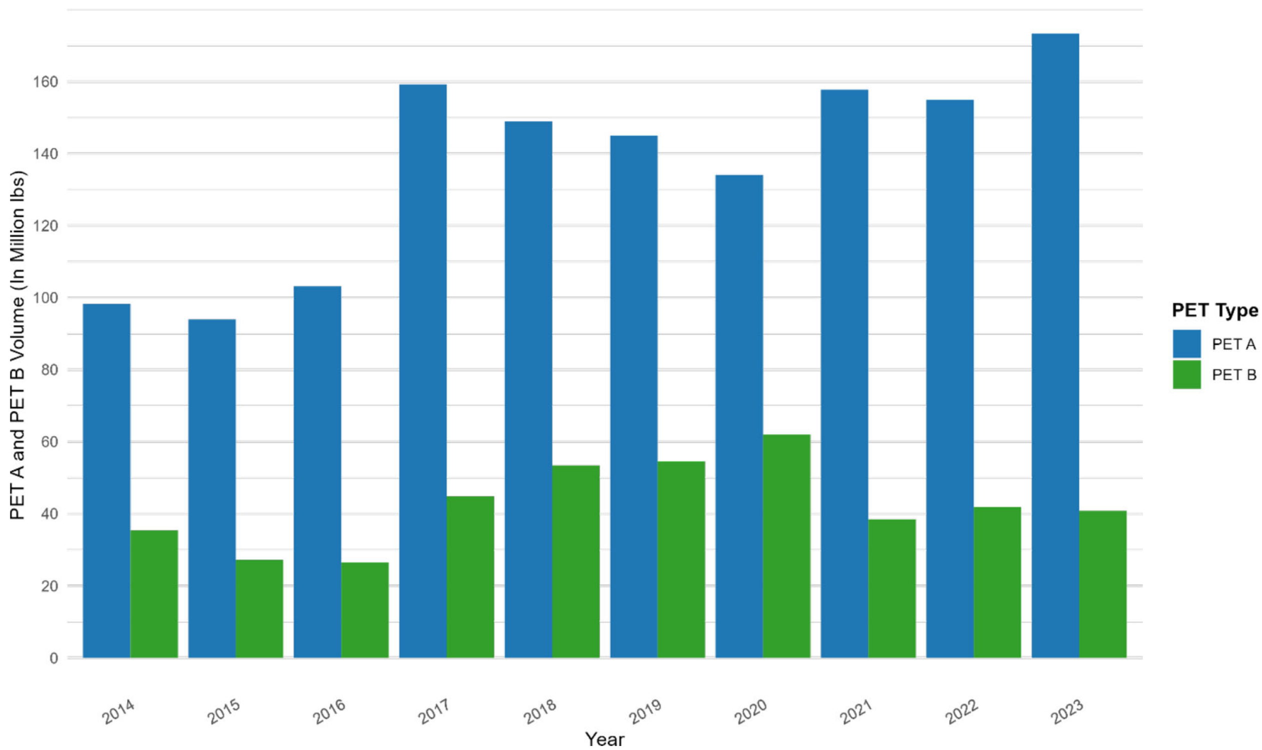

FIGURE 1. Quantity of PRCC recycled plastic traded, 2014–2023.

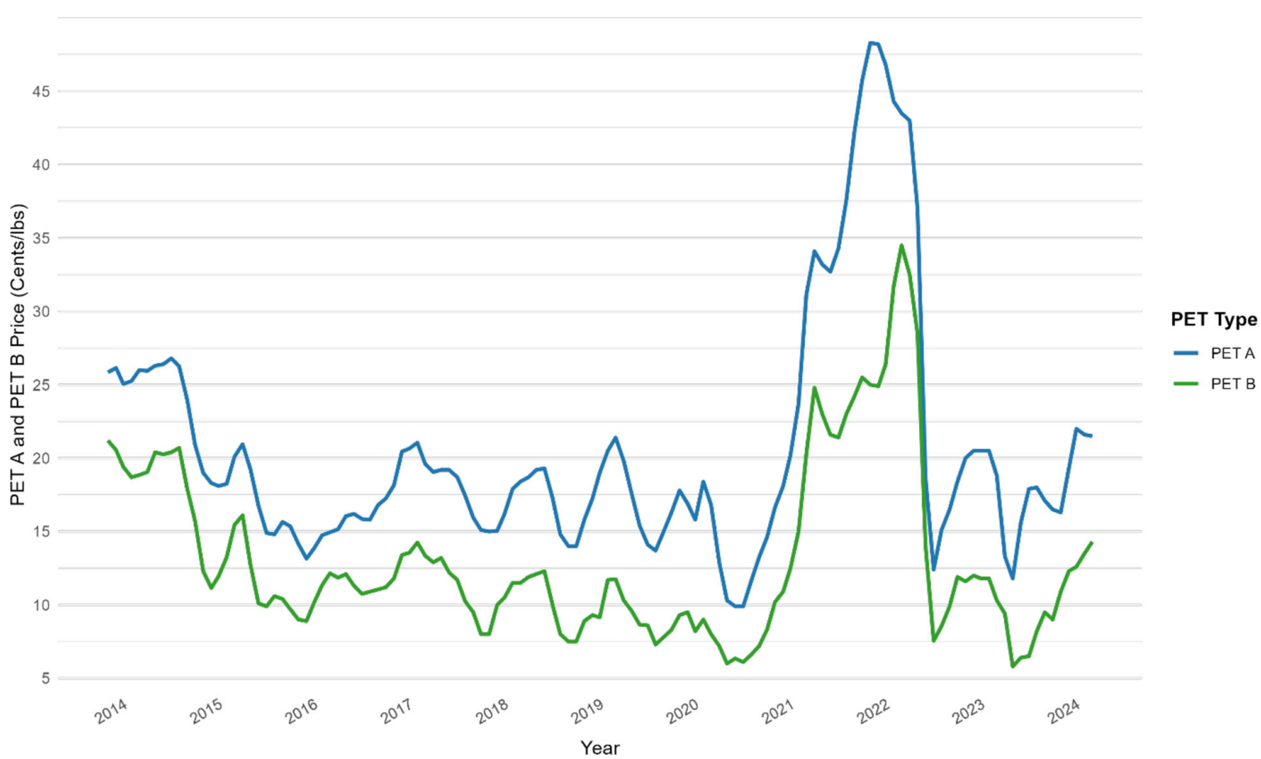

FIGURE 2. Auction prices of PRCC recycled plastic, 2014–2023.

swings over the years. However, the general trend suggests that PET A prices have tended to be higher than PET B prices, with the gap widening in recent years. It is clear from the data that the two PET prices are positively correlated—in other words, demand for recycled plastic of all grades goes up and down in lockstep.

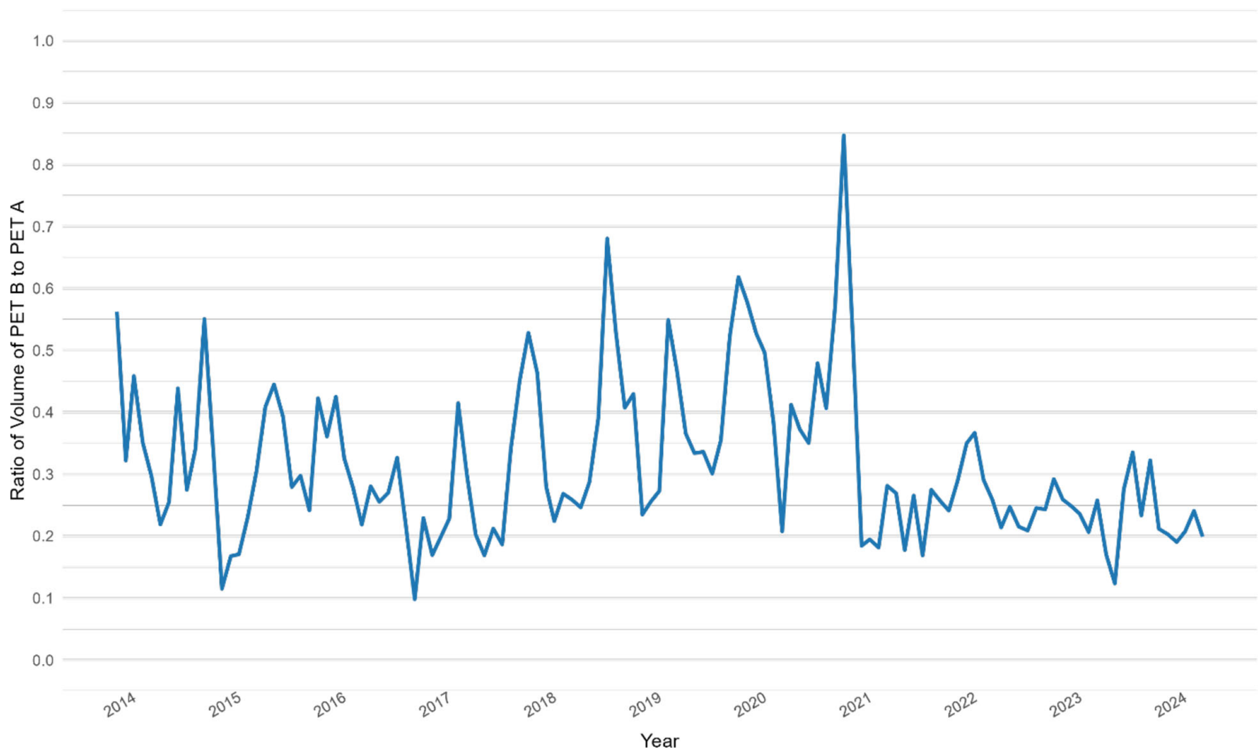

FIGURE 3. Relative volume ratio of Grade B to Grade A PRCC recycled plastic, 2014–2023.

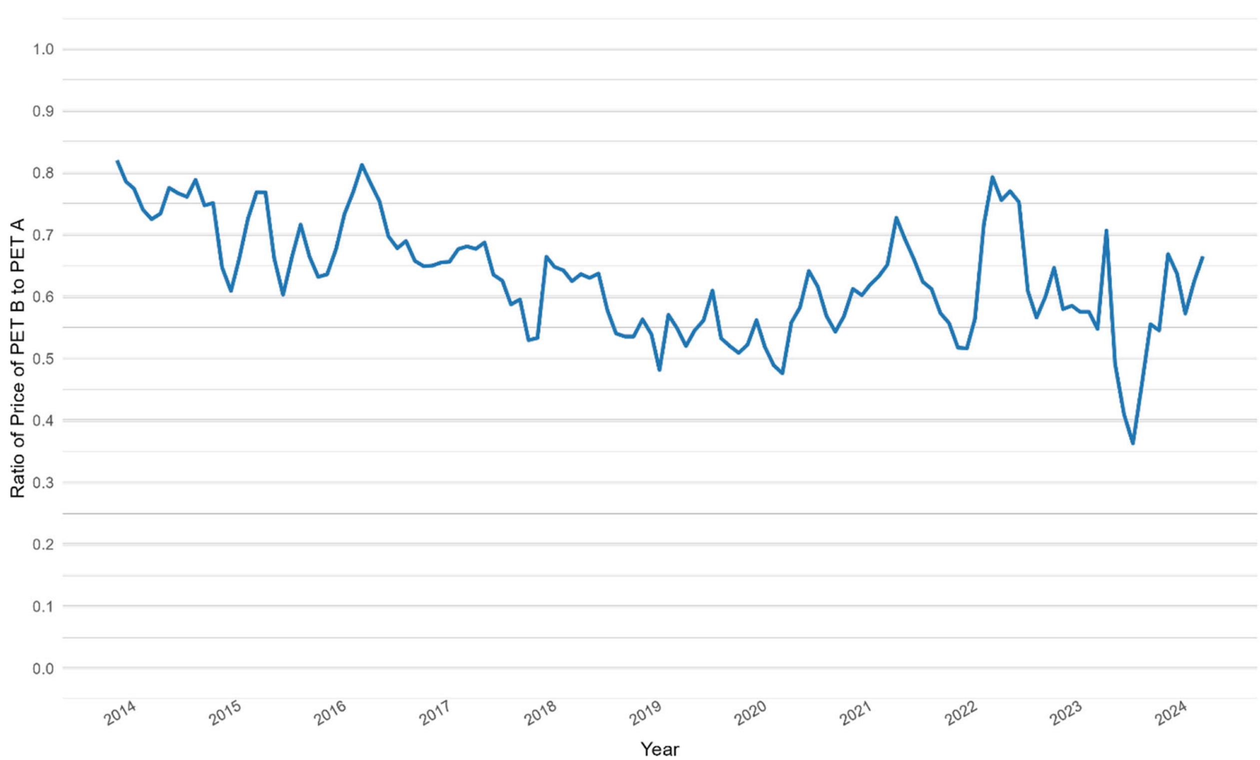

FIGURE 4. Relative price ratio of Grade B to Grade A PRCC recycled plastic, 2014–2023.

Figures 3 and 4 show the time trend in the relative volumes and relative prices for the two grades of plastic. We analyze the time trend in the volume ratio of PET B to PET A using a regression framework, and the results of this analysis show a negative and statistically significant time trend in the volume ratio. In other words, the average trading volume ratio of PET B to PET A decreases with each additional month since listing. We also analyze the time trend in the price ratio of PET B to PET A using the same regression framework. The results indicate a negative and statistically significant time trend in the price ratio. Taken together, declining prices and volumes over time show a relative decline in demand for the lower-grade PET B plastic. In other words, buyers and sellers are becoming relatively more active trading in the PET A contract. The "real world" interpretation of this trend is that buyers are demanding the higher-quality PET A bales required for creating recycled plastic material.

The availability of a transparent and robust market for the sale of recycled plastic provides incentives for market participants to engage in high-quality recycling. If you know what price you can receive for selling recycled plastic, you will be economically motivated to collect and recycle plastic waste if your collection and recycling costs are sufficiently low relative to the sale price. Furthermore, if you know the prices of both PET A and PET B plastic, you will be economically motivated to purchase PET B and upgrade it to PET A if your costs are sufficiently low. The listing of exchange-traded futures on recycled plastic would provide waste management firms and other natural sellers the ability to "lock in" their future sale price so they were not exposed to price volatility during the time necessary to collect and recycle plastic waste.

Demand for PET A plastic has grown relative to other grades of recycled plastic. Therefore, a futures contract on PET A plastic is more likely to generate traction among buyers and sellers than a futures contract on any other grade of recycled plastic. We can shift our focus to the relative merits of listing cash-settled futures or physically settled futures on PET A plastic.

Physical Settlement

The following example illustrates how physical settlement works: suppose two parties exchange a contract representing one ton (two thousand pounds) of PRCC Grade A PET at 20 US cents/pound. On the expiration date, the auction price of PRCC Grade A PET is 21 US cents/pound. The "long" party—the one looking to buy the commodity—pays US$400 (20 US cents/pound × 2,000 pounds) to the "short" party and would receive 1 ton of PRCC Grade A PET in exchange when the contract reaches its expiration date. Futures contracts expire at regular intervals: some contracts expire quarterly, others monthly, and others more frequently than that even. It would be on or around those predetermined dates that physical material would change hands as per the terms of the contract.

The original futures contract was settled by physical delivery of the underlying asset from the seller to the buyer, and the delivery of the agreed upon cash purchase price from the buyer to the seller. All the futures contracts that initially traded in the United States on the Chicago Board of Trade in 1948 utilized physical settlement. Much of the logistics of physical delivery are specified in contract settlement terms, such as specifications on the quality or grade of the underlying asset, a list of acceptable delivery locations, and so on. These covenants protect market participants from possibly undesirable surprises upon delivery, such as having to pick up from some remote location or paying exorbitant shipping fees. Today's physically settled contracts typically operate by specifying a list of warehouses capable of storing the commodity, and "taking delivery" can be as simple as a transfer of a warehouse receipt or shipping certificate. Upon taking possession of title to the goods, one may continue keeping them in the warehouse, as long as one continues to pay the requisite storage costs, and, assuming the commodity is nonperishable, reuse it as collateral for new futures contracts. A warehouse system also makes it easier to perform other functions to eliminate potential problems or fraud, such as maintaining physical security of the goods, conducting independent inspections for material quality and quantity, and so forth.

Buyers and sellers of physically settled futures contracts can trade in and out of their positions without waiting for expiration and delivery. For example, the buyer of the one-ton contract from earlier, where the PRCC Grade A PET price was agreed at 20 US cents/pound could also sell the contract before the expiration date. If the new buyer agreed to a price of 22 US cents/pound, the seller would earn a profit of US$40 (2,000 pounds × (US$0.22 sale price/pound − US$0.20 purchase price/pound)). In modern futures markets, less than 10% of all contracts purchased are held until expiration for physical delivery. Investors with either "long" or "short" futures also frequently "roll" their positions into new contracts, by closing their contracts shortly before the expiration date and entering new positions in contracts on the same underlying with featuring the next expiration date. The eventual physical delivery at maturity naturally results in a convergence between the price in the futures market and that in the spot market, adjusting for storage costs. If this were not the case, there would be an immediate arbitrage opportunity where someone could buy or sell a contract for a higher or lower price on the futures exchange and meet their obligation for physical material delivery in the spot market, leading to an immediate profit.

Cash Settlement

Futures contracts with cash settlement expire at the price of some transparent, robust index that is widely held to be valid by both market participants and financial regulators. To return to the example above for physical settlement: on the contract expiration date, say the index price of PRCC Grade A PET is 21 US cents/pound. Parties with long or short positions would still settle their profit and loss based on the closing price of the index—but they would not actually exchange the physical commodity. So, the "long" party—the buyer of the contract priced at 20 US cents/pound—would receive US$20 from the "short" party, since the index price was 21 US cents/pound, one cent higher than the price they had agreed upon.

The main value of a cash-settled approach is utilizing market mechanisms to establish price, hedge risk, and determine information about supply and demand. Even though at first cash-settled futures do not appear to facilitate the actual movement of commodities, in practice they do play a valuable role. For instance, a company that makes packaging from recycled PET (rPET) plastic might be concerned that prices for this material might rise in the next 3 months, due to rising demand or supply chain disruptions. Imagine that today's market price for rPET is US$500 per metric ton. Imagine the company has limited space to store enormous amounts of material at this attractive price. The company could enter into a cash-settled futures contract to buy rPET at US$510 per metric ton in 3 months. After that amount of time passes, the cash-settled futures contract could be beneficial whether prices rise or fall. For example, if prices for rPET rise on the spot market, say to US$550 per ton, the company would earn US$40 per contract: US$550 (spot price) − US$510 (price specified in contract) = US$40 that the company could use to offset the rise in prices that occurred in the spot market. Conversely, if spot prices for rPET fell, say to US$480 per metric ton, the company will lose US$30 per ton on the futures contract but could still go buy rPET in the market at the lower price—still paying essentially US$510 per ton. Thus, cash-settled futures contracts function to lock in a price for a commodity, whether prices in the spot market increase or decrease.

CONCLUSION

At first glance, cash settlement might seem a better route for futures contracts on recyclable material. Physical settlement means that all manner of logistics must also be considered in the contract, and these could be enormously complex to navigate, in contrast to the "cleaner" mechanism of simply settling price differences between contract holders. However, cash settlement has a stiff obligation requiring the creation of a credible, regulator-approved index that is demonstrably free from market manipulation, and this is no small task in a market that has been as historically as opaque as that for recycled materials. Conversely, while the logistics of physical settlement are considerable in terms of physical space needs and requirements for a system for warehousing, inspecting, and tracking material, physical settlement has a much more straightforward set of regulatory hurdles to clear. Furthermore, the fact that physical material is a part of physical delivery—meaning that a buyer may well end up with a warehouse full of material to have to manage—disciplines market participants and limits runaway speculation which can distort price signals.

In either case, listing exchange-traded futures contracts for recycled materials, particularly PRCC's Grade A PET plastic, presents a transformative opportunity to address inefficiencies in the recycling market. By establishing a regulated platform that facilitates transparent pricing, improves market liquidity, and reduces price volatility, these contracts can enhance the economic viability of using recycled materials in manufacturing. Ultimately, the adoption of postconsumer materials-linked futures contracts has far-reaching implications for environmental sustainability and economic efficiency. By incentivizing higher-quality recycling practices, supporting manufacturers' commitments to sustainability, and enabling better alignment of supply and demand, this innovation could significantly bolster the recycling ecosystem. As the PRCC's auction data illustrates, the growing interest in recycled plastics underscores the urgency of advancing market mechanisms to meet this demand. Policymakers, industry stakeholders, and market participants must collaborate to overcome logistical, regulatory, and technical challenges, ensuring that exchange-traded futures on recycled materials become a cornerstone of the circular economy.

CASE STUDY QUESTIONS

1. Do you agree with the authors that PRCC Grade A PET would make an excellent first test for issuing and trading futures contracts on recycled materials? Which other types of recycled materials do you think make the most sense for futures contracts?

2. The optimal contract size for futures contracts on recycled material must be large enough to attract major purchasers, but small enough to be feasible for smaller recycling firms and manufacturers. What would you recommend as the ideal contract size (e.g., how many tons of material should each contract represent?)

3. How frequently should futures contracts on PRCC recycled plastic expire? Should the contracts expire every 2 weeks when the PRCC holds a new auction? Or should the contracts expire every 3 months in line with other types of commodity futures contracts? What are the problems with having futures contracts that expire too frequently or too infrequently?

4. One argument in favor of cash settlement is that the contracts can be traded by a global market instead of a local market. Greater market participation would increase liquidity and decrease volatility. Do you think that investors outside California would actively trade a cash-settled futures contract on California recycled plastic? Why or why not?

5. For a marketplace to thrive, you need active participation from three groups: (1) natural buyers (such as manufacturers interested in using recycled materials), (2) natural sellers (such as waste management and recycling processing firms), and (3) liquidity providers (such as market makers). How would you go about pitching each of the three groups on the benefits to them for participating in the futures exchange for recycled plastic?

6. Overall, do you recommend cash-settled or physically settled futures contracts on recycled materials? Why?

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, data collection, formal analysis, writing—original draft, writing—review and editing, visualization, project administration, funding acquisition: JM, JPH.
Data collection, formal analysis, visualization: AK.

COMPETING INTERESTS

None

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SUPPLEMENTAL MATERIAL

Teaching Notes.docx

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