Reducing plastic pollution in food packaging: Should we tax virgin plastic consumers or producers?

Nabin Bhandari[a] and Ruiqing Miao[a]

[a] Department of Agricultural Economics and Rural Sociology, Auburn University, USA

[Preliminary Draft – Do Not Cite]

Selected paper prepared for presentation at the 2025 AAEA & WAEA Joint Annual Meeting in Denver, CO; July 27-29, 2025

Reducing plastic pollution in food packaging: Should we tax virgin plastic consumers or producers?

Abstract: A key feature of circular economy is the economic connection between virgin firms and recycling firms. We develop a conceptual framework to study the impact of taxing virgin plastic consumers with money back policy (TCMB) and, separately, taxing virgin plastic producers (TP) on total social welfare in the U.S. plastic market under two scenarios (virgin and recycling plastic firms economically connected (scenario I) vs independent (scenario II)). We find that taxing consumers with money back (TCMB) policy is superior to taxing producers (TP) to reduce the landfill quantity in both scenarios. For example, under 10% tax (in both TCMB and TP) policy and the assumption of 10% of the used virgin plastic returned to collection centers and 30% of tax amount being returned to consumers in TCMB policy, we find that the landfill quantity is 64% and 62% of virgin plastic produced in scenario I and scenario II, respectively under TCMB policy. However, in TP policy, the landfill quantity is 74% (scenario I) and 74.6% (scenario II) of produced virgin plastic. Accounting the environmental damage cost associated with production of virgin plastic, taxing either consumer or producer increases the total social welfare (TSW) in the U.S. plastic market compared to the no policy scenario. Under scenario II, TCMB and TP generate 23% and 15.67%, respectively, additional total social welfare in the plastic market compared to the benchmark scenario.

Key words: environmental damage cost, social welfare, tax, virgin plastic

JEL codes: Q38, Q53

1. Introduction

Plastic products have countless advantages for human beings. However, a substantial increase in plastic pollution has raised concerns about negative impacts on the global economy, ecosystem, and human and animal health (Syberg et al., 2015; Geyer et al., 2017; Prata et al., 2019; Chen et al., 2021; Tejaswini et al., 2022; Vaio et al., 2022). On a global scale, the plastic industry generates more than 400 MMt of non-biodegradable plastic waste annually, yet less than 20% is managed properly (Lampitt et al., 2023). The food packaging alone generates 40% of global plastic waste (Cottom et al., 2024). As plastic production is expected to double by 2050 and only a few portions of used plastic (about 9%) are being recycled globally (Singh and Walker, 2024), policymakers are currently considering possible measures to reduce the production of single-use plastic products and increase plastic recycling. For instance, on March 2, 2022, 170 countries agreed to implement a global legal treaty to end plastic pollution (United Nations Environment Programme, 2022).

Tax on virgin plastic production or consumption is one of the major policy instruments to reduce plastic pollution. To the best of our knowledge, however, no studies have considered the economic connection between recycling and virgin plastic-producing firms to analyze the overall welfare impact of the tax. In contrast to previous studies' assumptions, a key feature of the circular economy is that the input of recycling firms is constrained by the output of material recovery facilities (MRFs). A MRF cleans and processes the used plastic and then makes it available to the recycling firm. Recycling firms produce products by using recycled virgin plastic pallets contributed by MRFs. The output of MRFs depends upon the availability of used virgin plastic and the cost of gathering and processing the used plastic. The change in the cost of MRF is the shifter of the supply curve facing the recycling firm, because MRF is the primary input material for recycling firms to produce recycled plastic. Studies ignoring this dependency of recycling firms on used output of virgin firms' may generate misleading predictions on the impact of policy interventions. The purpose of this article is to fill this gap by developing a conceptual framework to study the impact of tax in the plastic market accounting the interaction between virgin firms and recycling firms.

A few studies that investigate the tax policy impact on waste management and on transition to cleaning activities neglect the principal feature of circular economy. In addition, these previous studies ignore the policy impact on total social welfare. For example, in Fullerton and Wolverton (2000, 2005) clean and conventional activities are assumed to be independent. In Acemoglu et al.'s (2016) study for the transition to clean technology, clean and conventional firms are modeled to compete with each other. Similarly, Weerdt et al. (2021) evaluate the plastic investors' behavior in the context of policy uncertainty but neglect policy effect in total social welfare. In addition, a few other studies evaluate the impact of tax on the behavior of virgin plastic consumers without quantifying tax impact on plastic markets from total welfare perspectives (e.g., Convery et al., 2007; Martinho et al., 2017; Senturk and Dumludag, 2021).

In contrast to the above studies, we account the economic connection between virgin and recycling firms and quantify the two forms of tax impact on total social welfare in the plastic market. Specifically, we compare the change in producer surplus (PS), consumer surplus (CS), government expenditure (GE), environmental damage cost (EDC), and total welfare (TW) under taxing virgin plastic consumers with money back policy (TCMB) and, separately, under taxing virgin plastic producers (TP) to identify conditions under which one policy instrument has a more incentivizing effect (greater social welfare) than the other in the plastic market. We consider two scenarios for each type of tax (TCMB vs.TP). In scenario I, regardless of the choice of policy interventions (TCMB vs. TP), the supply quantity and price of recycled plastic does not change. However, under scenario II, when consumers are incentivized under TCMB policy to return used plastic to collection centers, it reduces the search cost for MRFs, enabling them to supply larger quantities at lower prices to recycling firms. This reduction in the input costs of recycling firms shifts the supply curve to the right. We also consider the benchmark scenario (no policy) to compare results. Furthermore, we quantify the effect of the two types of taxes in reducing landfill quantity Q_L, Landfill Tipping Cost (LTC), and total carbon dioxide emission (TCO2) in the environment.

Offering consumers a partial refund for returning used plastic products is an example of incentivizing plastic users to recycle (Environmental Protection Agency, 2024). In USA, although there is no federal regulation regarding the deposit refund scheme of plastic waste management, states such as California, Connecticut, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon, and Vermont have already established this system (National Conference for State legislatures, 2024).

The reminder of this paper is organized as follows. Section 2 presents the background of the plastic market to familiarize readers with the actors and the recycling process of plastic in the U.S. Section 3 presents the conceptual framework used to develop toy models to study the impact of policies in the social welfare of virgin and recycled plastic market. Section 4 presents the data and model calibration. In section 5, we graphically present the welfare analysis and amount of landfill quantity in different policy scenarios. Then, we develop the demand and supply curve for virgin and recycled plastic in the U.S. followed by the discussion of the impacts of two different forms of tax on consumer surplus, producer surplus, and social welfare in plastic market. We also discuss the impact of each policy on quantity of plastic on landfill Q_L, Landfill

Tip Cost (LTC) of used plastic, and CO2 emission (TCO2) in producing recycling and virgin plastic. Section 6 concludes.

2. Background

The plastic market engages many stakeholders. Figure 1 represents a typical flow of plastic commodities and actors involved in the plastic market. First, converters convert natural oil, gas, or coal to virgin plastic pellets. Manufacturers of virgin plastic products melt and reshape plastic pellets producing desired products. Used plastic products are kept either in curbside collection boxes or bins, drop-off centers or utilized for deposit or refund programs, or are managed by burning and dumping. The responsibility of who collects curbside recycling in the U.S. differs greatly depending on the state and the county (The Recycling Partnership, 2016). Furthermore, some retailers, centers, and groceries accept and collect plastic bags, wraps, and films for recycling. Sometimes residents take waste directly to landfills, waterbodies, or Material Recovery Facility (MRF). There are 375 MRFs in the U.S. (Greenpeace, 2022).

After collection from different sources, the used plastics are sent to a Materials Recovery Facility (MRF), which plays a key role in recycling. The MRF segregates, cleans, dries, and densifies used plastic to prepare recycled plastic. The availability of raw materials to recycled plastic manufacturers depends upon the quantity of used plastic available for MRF. For example, if the tax on the virgin plastic market reduces the availability of used plastic for MRF, then it might create difficulties for MRF in collecting the used virgin plastic. In turn, it raises the input cost of downstream converters and recycled plastic manufacturers. Recycling manufacturing firms convert recyclable materials obtained from MRF to new products. According to ENF (2023), in the U.S. there are 194 recycling plants (ENF, 2023).

According to Global Research Consulting (2020), the U.S. plastic industry consists of 15,746 manufacturing establishments giving employment to around 800,000 employees. Established recycling firms vertically integrate and produce diversified products to compete with the virgin plastic industry (Hadjilambrinos, 1999). The global recycled plastic market size is USD 41.13 billion (only 6.5% share of the total plastic market) whereas the virgin plastic market is around 593 billion in 2020 (Fortune Business insights, 2021; Statista, 2023).

3. Conceptual framework

In this section, we develop a conceptual framework to study the impact of two forms of tax policy (TCMB vs TP) on CS, PS, and TSW in the plastic market of the U.S. As mentioned above, we consider two scenarios (Scenario I and Scenario II) under each form of tax policy. We also analyze the quantity of used plastic that ends up in landfills without recycling or without being combusted with energy recovery.[1]

To make the model simple and tractable, we consider two major actors in the plastic markets. One is virgin plastic firm that produce virgin plastic from oil, coal, and natural gases and the other is recycling firm that produce recycled plastic from used virgin plastic.[2] As the market size of recycled plastic is only 6.5% of the total share of the plastic market, we assume that the change in demand and supply of the recycled market does not affect the virgin plastic market. The quantity of virgin plastic produced is denoted as Q_V and the quantity of recycled

1 Environmental protection Agency of USA (EPA, 2020), defines combustion with energy recovery as "combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel)."

2 Assuming 1 firm for one type of plastic will generate the same quantitative results as does assuming infinite number of firms that produce one unit of plastic each. Because the aggregate supply curve is the same.

plastic by Q_R. In addition, we assume the price of virgin and recycled plastic to be P_V and P_R, respectively. Furthermore, we assume that firms are facing a competitive market structure. Since firms are price takers, under tax policy marginal virgin plastic firms will exit from the market and only low-cost virgin plastic producing firms will survive and continue producing the virgin plastic. Furthermore, for both firms we assume the cost function to be convex i.e, C_V' $(\cdot) > 0$, C_R' $(\cdot) > 0$ and C_R'' $(\cdot) > 0$ and $C_V''(\cdot) > 0$, where C_V and C_R denotes the cost function of virgin plastic firm and recycling firm, respectively.

The recycling firm obtains its principal input from MRF (Figure 1). The supply curve S_R of recycling firm shifts as the cost of the MRF changes to the recycling firm. The used virgin plastic that is not recycled is Q_{UR}.Therefore, the total quantity of virgin plastic produced by a virgin plastic-producing firm can be written as,

$$Q_V = Q_{UR} + Q_{MRF.} \tag{1}$$

We assume that there is no loss of plastic in the recycling process i.e., $Q_{MRF} = Q_R = \alpha Q_V$, where $\alpha \in [0,1]$ is the fraction of the used virgin plastic Q_V that is proceed in MRF to produce recycled plastic Q_R. Furthermore, we assume that used virgin plastic can only be recycled once. In addition, quantity of used virgin plastic that is combustion with energy recovery $Q_E = \beta Q_V$, where $\beta \in [0,1]$ is the fraction of the used virgin plastic Q_V that is utilized for combustion with energy recovery. Furthermore, the quantity of used virgin plastic that is returned due to the money back policy $Q_{MB} = \gamma Q_V$, where $\gamma \in [0,1]$ is the fraction of the used virgin plastic Q_V that consumer's return to get certain portion of their expense on virgin plastic. The quantity of used plastic that does not enter the recycling or energy recovery process and is not returned for monetary incentives is Q_L. We assume that Q_L either ends up in landfills or water bodies and called this quantity as landfill quantity. Under these assumptions, landfill quantity Q_L is given by,

$$Q_L = Q_V - Q_R - Q_E - Q_{MB} = Q_V - \alpha Q_V - \beta Q_V - \gamma Q_V. \quad (2)$$

According to EPA (2024), the recycling rate of used plastic and rate of used plastic combusted with energy recovery is 8.7% and 16.3%, respectively.[3] Therefore, in the benchmark scenario of welfare estimation α takes value 0.087. While we keep value of β (0.163) constant in each scenario.

Let, P^* and Q^* denotes the equilibrium price and quantity in the plastic market. Then for each plastic market,

$$CS = \int_{P^*}^{P_{max}} Q(P)dP \quad (3)$$

$$PS = \int_{P_{min}}^{P^*} Q(P)dP \quad (4)$$

where P_{max} is the maximum price, the consumers are willing to pay and P_{min} is the minimum supply price of plastic in question (i.e., recycling or virgin). The TW for each plastic market under each policy scenario can be represented,

$$TW = CS + PS + GR - GE - EDC, \quad (5)$$

EDC for virgin plastic market is defined as:

$$EDC = \delta Q_V, \quad (6)$$

where, δ is the environmental damage (in dollars) associated with the production of one ton of virgin plastic concerning climate change. Abate and Elofsson (2024) have estimated that one ton production and consumption of virgin plastic causes environmental damage worth of $2,500.[4]

---

[3] Environmental Protection Agency (EPA). Plastics: Material-Specific Data | US EPA.

[4] According to Abate and Elofsson (2024) estimates, the environmental damage costs (in $) concerning climate change for per unit of plastic bag is 0.025. Furthermore, the weight of 1

Similarly, to further explore the management and environmental cost associated with the production and consumption of plastic we quantify the LTC for managing used virgin plastic, and total amount of CO2 emission (TCO2) in producing recycling and virgin plastic under different policy scenarios. According to Resource Recycling (2023), ton weighted average LTC for used virgin plastic in U.S. is \$ 60.34 per ton.[5] Therefore,

$$LTC = 60.34 * Q_L (in\ tons). \tag{7}$$

Also, the total amount of CO2 emission in producing recycled and virgin plastic is:

$$\mathrm{TCO2} = \Psi * Q\ (in\ kg). \tag{8}$$

where Ψ is the CO2 gas emission kilogram equivalent per kg of plastic produced. The value of Ψ is assumed to be 1.865 for virgin plastic and 0.54 for recycled plastic.[6] In equation (8), Q is the quantity of plastic in question (virgin vs. recycled).

Demand and supply function estimation

Virgin plastic

Using current scenarios of U.S. plastic production and price, we estimate the demand and supply function of virgin and recycled plastic in the U.S. market. We utilize the concept of arc elasticity to approximate the percentage change in quantity based on the percentage change in price. Using the midpoint of the price change, arc elasticity gives the approximate price elasticity at any point

---

plastic bag is assumed to be 10 grams. Therefore, 1 ton of plastic production accounts for \$ 2,500 environmental damage concerning climate change.

[5] Report available at https://resource-recycling.com/recycling/2023/06/12/us-landfilling-costs-jumped-sharply-last-year/.

[6] Association of plastic recycles documents that 1 kg of virgin HDPE and 1 kg of virgin PP contributes 1.89 and 1.84 kg CO2 Equivalent. Whereas that of 1 Kg HDPE and 1 Kg PP from recycled resign generates 0.56 and 0.54 Kg CO2 Equivalent. For our analysis, we use the mean value; for virgin 1.865 kg CO2 Equivalent and for recycled 0.55 kg CO2 Equivalent. Available https://plasticsrecycling.org/wp-content/uploads/2024/08/APR-Recycled-vs-Virgin-LCA-May2020.pdf. Accessed on December 23, 2024.

on the curve (Allen, 1934). Following Porter (2002), we define the arc price elasticity of demand of virgin plastic ($\varepsilon_{p,v}$) as follows:

$$\varepsilon_{p,v}=\frac{\frac{X_1-Q_V}{(X_1+Q_V)/2}}{\frac{P_1-P_V}{(P_1+P_V)/2}} \tag{9}$$

where Q_V is the demand of virgin plastic when the price of the virgin plastic is P_V. Similarly, X_1 is the demand when the price is P_1. From equation (9), $X_1=\frac{Q_V(\Delta P\varepsilon_{p,v}+P)}{P_1-\Delta P\varepsilon_{p,v}}$, where $\Delta P=P_1-P_V$, and $P=P_v+P_1$. According to Statista (2024), in 2019 the production of polyethylene was 22,674 thousand tons (see Appendix Figure 1). According to RecycleINME (2024) the average price of plastic in the U.S. is 1620 per ton (see appendix Table 1). Therefore, in benchmark scenario $P_V=\$\,1{,}620$/ton and Q_V = 22,674 (in thousand tons).

We assume that the minimum supply price of the virgin plastic is γP_V , where $\gamma \in [0,1]$ is the fraction of the equilibrium price P_V. Based on Abate and Elofsson (2024), we assume arc elasticity of virgin plastic ($\varepsilon_{p,v}$) to be -1.22. Under consideration of 10% increase in price, equation (9) yields X_1= 20,184, and slope of demand curve ($\frac{dQ}{dP}$) = -15.37. Therefore, the demand curve in the U.S. virgin plastic market is:

$$Q_{V,d}= -15.37P_V+3095 \tag{10}$$[7]

Inverse demand curve,

$$P_V= -0.065Q_{V,d} +3095.26 \tag{11}$$

We assume the value of supply elasticity to be the same as the absolute value of demand elasticity in the virgin plastic market. In addition, the supply price of virgin plastic is assumed to

[7] We substituted the value of equilibrium quantity in demand curve $Q_V=a+bP_V$ and solved for the maximum wiliness to pay parameter (a).

be half of the equilibrium price P_V at the benchmark scenario. Under these assumptions, the supply equation of virgin plastic is,

$$Q_{V,s}=17.08P_V-13{,}831 \quad (12)$$

[8]

Inverse supply curve,

$$P_V= 0.0585Q_{V,s} +810 \quad (13)$$

Recycling plastic

Based on the U.S. current rate of recycling, the quantity of recycled plastic produced Q_R is 1,973 (in thousand tons). We assume P_R to be σP_V, where σ =1.25. Furthermore, under the assumption of price elasticity of demand for recycling plastic $\varepsilon_{p,R} = -1$ (i.e., we assume recycling plastic is less elastic than the virgin plastic), and 10% increase in the price we get demand (X_2 in equation (9)) of recycling plastic to be 1,793 (thousand tons). The slope of the demand curve for recycling plastic is -0.87. Under this approximation, the demand curve of recycling plastic in benchmark scenario is,

$$Q_{R,d} = -0.89P_R+ 4252 \quad (14)$$

$$P_R= -1.12\ Q_{R,d} + 4{,}777.5 \quad (15)$$

As in virgin plastic market, we assume the value of supply elasticity to be the same as the absolute value of demand elasticity in the recycling market and supply price $P_{min,r}$ of recycled plastic is 0.5 times the equilibrium price P_R at benchmark scenario. From these assumptions, the supply equation of recycled plastic is:

$$Q_{R,s} = 0.97(P_R - 1012.5) \quad (16)$$

[8] Elasticity (ε)= $\frac{dQ}{dP} * \frac{P}{Q}$. Therefore, $\frac{dQ}{dP} = \varepsilon * \frac{Q}{P}$ and supply curve $Q_{V,s} = b(P_V - P_{min,v})$, where P_{min} is supply price and in our analysis we assume it as 0.5 of the equilibrium price.

where 0.97 is the slope of the supply curve, and 1012.5 is the minimum supply price of recycled plastic.

The inverse supply curve:

$$P_R = 1.03Q_{R,s} + 986.32 \quad (17)$$

A summary of these assumptions considered derive the demand and supply curves for both plastic types, and to quantify the total welfare from producing virgin and recycled plastic under different policy scenarios, is presented in Table 2.

4. Policy impact on welfare, landfill quantity, and environmental damage cost

In this section first, we present the CS, PS, GE, GR, and TSW under different policy scenarios in Figure 2, 3, and 4. Figure 2 represents the benchmark scenario. Figure 3 represents scenario I, where the virgin firms and recycling plastic firms are not economically connected. Similarly, Figure 4 represents scenario II, where virgin and recycling firms are economically connected to each other.

4.1 Benchmark scenario

As a benchmark of our analysis, we present the welfare analysis in the case of laissez-faire in Figure 2. Let CS_V^0 and PS_V^0 denotes CS and PS in a benchmark scenario in the virgin plastic market. From Figure 2 (a),

$$CS_V^0 = \Delta \text{AE}P_v,\ PS_V^0 = \Delta \text{BE}P_v\ . \quad (18)$$

Similarly, from Figure 2(b), CS and PS in recycling plastic market denoted by CS_R^0 and PS_R^0 is,

$$CS_R^0 = \Delta \text{KM}P_R,\ PS_R^0 = \Delta \text{LM}P_R\ . \quad (19)$$

4.2 Scenario I: TCMB vs TP

In Figure 3, we present TCMB (panel a) and TP (panel b) policy impact on CS, PS, and TW under Scenario I. In Graph a, we show the impact of TCMB on virgin plastic market. With tax on consumers, the demand curve will shift towards left to D'_V . The new equilibrium quantity demanded under this tax is $Q_{V,t}$. The price paid by the consumer and price received by producer is $P_{v,tc}$ and $P_{v,tp}$, respectively.

Let us suppose that Q_{MB} is the amount of used plastic that consumer returns to collection centers under TCMB policy. Then, the consumer surplus (CS_V^{MB}) and producer surplus (PS_V^{MB}) under TCMB is,

$$CS_V^{MB} = \Delta \mathrm{AK} P_{V,tc} + MB,\ PS_V^{MB} = \Delta \mathrm{BI} P_{V,tP} \quad (20)$$

where MB denotes the money that the consumer gets back by returning Q_{MB} amount of used plastic in the price P_{MB}. The government expenditure for money back (MB) policy $GE_V^{t,mb}$ is $Q_{MB}*P_{MB}$ and government revenue is $GR_V^{t,mb}$, where $GR_V^{t,mb} = Q_{V,t} * (P_{v,tc} - P_{v,tp})$.[9]

Similarly, the consumer surplus (CS_V^{TP}) and producer surplus (PS_V^{TP}) under TP policy scenario (Figure 3(b)) is,

$$CS_V^{TP} = \Delta \mathrm{AH'} P_{V,tc'},\ PS_V^{TP} = \Delta \mathrm{BI'} P_{V,tp'} \quad (21)$$

The government revenue is $GR_V^T = Q_{V,t} * (P_{v,tc'} - P_{v,tp'})$. Given the supply elasticity $e_{S,pv}$ and demand elasticity $e_{D,pv}$ of virgin plastic, the price paid by the virgin plastic consumer ($P_{v,tc}^*$) under tax t is (see appendix for details):

$$P_{v,tc}^* = P_v^* + \frac{e_{S,pv}}{e_{s,pv} + |e_{D,pv}|} \cdot t \quad (22)$$

Similarly, the price received by producer ($P_{v,tp}^*$), and quantity demanded ($Q_{v,t}^*$),

$$P_{v,tp}^* = P_{v,tc}^* - t \quad (23)$$

$$Q_{v,t}^* = Q_v^* - \frac{e_{S,pv}\, e_{D,pv}}{e_{S,pv} + |e_{D,pv}|} \cdot \frac{Q_v^*}{P_v^*} \cdot t \quad (24)$$

[9] Weather we assume money is returned through government channel or through producers, the total welfare in plastic market remains the same.

The deadweight (DW) loss,

$$\text{DW}=0.5 \cdot (\frac{t}{P_v^*})^2 \frac{e_{S,pv}\, e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} \cdot Q_v^* \cdot P_v^* \tag{25}$$

Price received by consumer, price paid by producer, equilibrium quantity, and deadweight loss under TP is presented in appendix.

4.3 Scenario II: TCMB vs TP

4.3.1 Scenario II: TCMB

Under scenario II, the welfare analysis in virgin plastic market is same as that under scenario I. Therefore, for scenario II, we discuss the changes in social welfare of recycling plastic market due to TCMB and TP polices. As described above, under TCMB the search and gathering cost of MRF decreases. As recycling firms produce products by using recycled virgin plastic pallets contributed by MRFs, the low price of pallets shifts the recycling firm supply curve towards the right as shown in Figure 4(e). We assume supply of recycling firms increases by ϕQ_{MB}, where $\phi \in [0,1]$ is the additional amount of recycled plastic produced under TCMB (expressed in fraction) when compared to benchmark scenario. The percentage change in price of recycling plastic under TCMB is,[10]

$$\%\text{ change in price } (\frac{(P_R{,}mb - P_R)}{P_R}) * 100 \;=\; \frac{\%\text{ change in supply } (\frac{(Q_{R,mb}-Q_R)}{Q_R}*100)}{elasticity\ of\ supply} \tag{26}$$

where $Q_{R,mb} = Q_R + \phi Q_{MB}$.

In the recycling market, the consumer surplus CS_R^{MB} and producer surplus PS_R^{MB} under TCMB policy is (Figure 4 (e)) is,

---

10 Equation (26) shows that the % change in price would be less significant relative to the increase in quantity supplied if the supply is elastic (>1). In our analysis, we have assumed the unitary supply elastic of recycling plastic. Therefore, % change in price is equal to % change in supply.

$$CS_R^{MB} = \Delta P_{R,mb}NK \text{ and } PS_R^{MB} = \Delta P_{R,mb}NT \quad (27)$$

4.3.2 Scenario II: TP

Under TP, the decrease in use of virgin plastic increases the search and processing cost of used plastic for MRF when compared to TCMB policy. This will shift the supply curve of recycling plastic to the left (Figure 4(g)) when compared to benchmark scenario (Figure 2(b)) or under Scenario I (Figure 3(c)).

Let us assume that the decrease in the supply of recycling plastic due to increased cost of MRF under TP in Scenario II is ϕQ_{MB}.[11] This helps us to calculate the % change in price using equation (26). From Figure 4 (g), the supply of recycled plastic is $Q_{R,tf}$ with price $P_{R,tf}$. The consumer surplus CS_R^{TP} and producer surplus PS_R^{TP} in recycling market is,

$$CS_R^{TP} = \Delta KN'P_{R,tf}, \text{ and } PS_R^{TP} = \Delta PNP_{r,tf}. \quad (28)$$

We summarize the CS, PS, GE, and GR for each scenario presented in Figures 2, 3, and 4 in Table 3. Similarly in Table 4, using equation (2) we also present the landfill quantity (Q_L).

5. Model description and calibration

We now use our conceptual framework and assumption presented in Table 2 to investigate the impact of TCMB and TP on the plastic market.

5.1 Social Welfare

Under our assumption, we calculate the CS, PS, GE, GR, EDC, and TSW are present in Table 5.[12] Under Scenario I, in virgin plastic market, CS in TCMB is higher than that in TP policy

[11] For simplicity we assume the decrease in supply of recycled plastic under TP is equal to quantity increased in the supply of recycled plastic under TCMB given the same amount of tax.
[12] Since we have no data regarding the environmental damage cost associated with recycled plastic, we assume that there is no environmental damage cost using recycled plastic. However, we have information regarding the total CO2 emission in producing recycled and virgin plastic which we present in Table 7.

because in TCMB policy some portion of consumer expenditure on plastic is returned. However, the PS and TSW under TCMB is equal to the PS and TSW under TP. Under this scenario for both policies (TCMB vs TP), the CS, and PS is less than that of benchmark scenario. If the absolute value of supply elasticity is more than that of demand elasticity in the virgin plastic market, the deadweight loss under taxing firms will be higher than taxing consumers with same percentage as for firms. Under scenario I, since the virgin and recycling firms are assumed to be independent, the TSW in the recycling market remains the same as that of benchmark scenario.

Under Scenario II, the consequences of taxes in the virgin plastic market are same as those under I. However, the value of social welfare components (CS, PS, and TSW) of the recycling market increases or decreases based on the type of tax on virgin plastic market. Under Scenario II with TCMB policy, the supply of recycled plastic increases there by decreasing the price of recycled plastic. Therefore, CS in the recycling market is higher than in both benchmark scenario or scenario I. However, holding the demand elasticity constant, the impact of additional supply of recycled plastic on PS in recycling market depends upon the supply elasticity. For example, if the supply is elastic (inelastic) holding demand elasticity constant, then producers are able to sell more recycled plastic at a slightly lower price (higher price) generating greater (lower more likely) PS when compared to benchmark scenario. Therefore, total welfare in the recycling market (CS+PS) under Scenario II and TCMB policy depends upon the elasticity of demand and supply.

Similarly, under scenario II with TP, the CS in the recycling market is lower than in the benchmark scenario. The PS can increase, or decrease based on the supply elasticity holding demand elasticity constant. For example, if supply is elastic, even with a large drop in quantity supplied there will be small increase in price of recycled plastic. This results in lower PS in scenario II with TP compared to benchmark scenario.

5.2 Landfill and recycled plastic quantity

Based on Table 4, we quantify the landfill quantity in different scenarios and present in Table 6. The landfill plastic and recycled plastic in benchmark scenario is 75% and 8.7% of the total production, respectively. In scenario I, under TCMB policy the landfill quantity is 10% points lower when compared to TP because we have assumed that 10% of the used plastic is returned by consumers for monetary incentives. In Scenario II, TCMB policy results 14% points lower landfill plastic compared to TP policy under our assumptions present in Table 4. The recycling rate under TCMB policy is 53% is higher than TP in Scenario II and due to two reasons. First, under tax policy as compared to benchmark scenario the quantity of virgin plastic is low in the plastic market. Second, some portion of the used virgin plastic is returned for monetary incentives which in turn increases the supply of recycled plastic in the market.

5.3 Landfill tip cost (LTC) and CO2 emission

In Table 7, we compare the Landfill tip cost associated with the management of virgin plastic in landfill and the total carbon dioxide generated in producing virgin and recycled plastic. At the benchmark scenario the LTC is 1026.11 billion and LTC changes as the landfill quantity changes based on policy as presented in Table 4. Exploring Table 6 and Table 7, we can say that although the TCMB policy may decrease the landfill plastic in Scenario II, it may increase total CO2 emission as some CO2 is emitted in producing additional recycled plastic. So, if the policy goal is to reduce TCO2 emission in atmosphere then TP can be superior to the TCMB in scenario II.

6. Conclusion

In this paper, we investigate the impact of two types of tax policy (taxing virgin plastic consumer with money back (TCMB)) and taxing virgin plastic firm (TP)) on plastic market. We consider two scenarios (Scenario I and Scenario II). In scenario I, virgin and recycled plastic market are not connected─policy on virgin plastic market does not affect the recycling market. Whereas in scenario II, policy impact on virgin plastic market is transferred to recycling plastic market (i.e., virgin plastic market and recycling market are connected). Specifically, we investigate policy impact on CS, PS, government expenditure and environmental damage cost in each scenario. We also quantify and compare landfill quantity, Landfill Tipping Cost (LTC), and total carbon dioxide emission (TCO2) in each scenario.

Based on our assumption, we find that taxing consumers with money back (TCMB) policy is superior compared to taxing firms (TP) to reduce the landfill quantity in both scenarios. The landfill tip cost is 13.49% and 18.38% lower in TCMB than in TP in scenario I and scenario II, respectively. Furthermore, when virgin and recycling firms are connected the total increase in social welfare compared to benchmarks scenario is higher in TCMB policy than in TP.

This paper contributes to the understanding of the effect of two common tax policies on total welfare in the plastic market. We also investigated how the policy on virgin plastic market impacts recycled plastic market. However, this investigation does not exhaust all possible conditions under tax matters. Such conditions could include but do not limit to different market structures, uncertainties in policy arrival and cost, and an increase in number of times the plastic can be recycled. Exploration of these policies under mentioned conditions may further enlarge our understanding of tax in increasing recycling of plastic to promote plastic circularity.

Reference

Acemoglu, D., U. Akcigit, D. Hanley, and W. Kerr. 2016. Transition to Clean Technology. *Journal of Political Economy* 124(11): 52-104.

Chen, Y., A.K. Awasthi, F. Wei, Q. Tan, and J. Li. 2021. Single–Use Plastics: Production, Usage, Disposal, and Adverse Impacts.*Science of the Total Environment* 752(2021) 141772: 1-15.

Abate, T.G., and Elofsson, K. 2024. Environmental taxation of plastic bags and substitutes: Balancing marine pollution and climate change. Journal of Environmental Management 359(2024)120868. https://doi.org/10.1016/j.jenvman.2024.120868.

ENF. 2023. Plastic Recycling Plants in U.S. Available at https://www.enfrecycling.com/directory/plastic-plant/United-States?page=2/[Accessed January 12, 2023].

Environmental Protection Agency (EPA), 2020. Advancing sustainable materials management: 2018 fact sheet. Assessing trends in material generation and management in the United States.

Environmental Protection Agency (EPA). 2024. Regulation and Policy.

Environmental Protection Agency. 2023a. Facts and Figures about Materials waste and recycling. Available at https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data/[Accessed January 1, 2023].

Environmental Protection Agency. 2023b. Frequent Questions on Recycling. Available at Frequent Questions on Recycling | US EPA. [Accessed January 1, 2023].

Fortune Business Insights, 2022. Recycled plastic market size, share & COVID-19 impact analysis, by type (Polyethylene terephthalate, high-density polyethylene, polypropylene, low-density polyethylene, and others), By application (Non-food packaging, food packaging, construction, automotive and others), and regional forecast, 2021-2028." Available at https://www.fortunebusinessinsights.com/infographics/recycled-plastic-market-102568. [Accessed on Jan 20, 2023].

Fullerton, D., and Wolverton, A. 2000. Two Generalizations of a Deposit–Refund System**.** *American Economic Review* 90 (2): 238-241.

Fullerton, D., and Wolverton, A. 2005. The two-part instrument in a second-best world. *Journal of Public Economics* 89 (9-10): 1961-1975.

Geyer, R., Jambeck, J.R., and Law K. L. 2017. Production, use, and fate of all plastics ever made. Science advances.2017; 3 (7):1-5.

Global Research Consulting. 2020. "US Plastics Market Size, Share & Trends Analysis Report by Material (Thermosets and Thermoplastics) and by Application (Packaging, Building & Construction, Automotive, Electrical & Electronics, Household, Leisure & Sports, Agriculture, and Others), Forecast 2020-2026." Available at US Plastics Market Size, Share, Growth and Report to 2026 (omrglobal.com). [Accessed on January 20, 2022].

Greenpeace. 2022. Circular Claims Fall Flat Again. Available at: www.greenpeace.org/usa/wp-content/uploads/2020/02/Greenpeace-Report-Circular-Claims-Fall-Flat.pdf./[Accessed on December 10, 2022].

Hadjilambrinos, C. 1999. **"**The USA plastics recycling industry: a survey of manufacturers and vendors of recycled plastic products.**"** *Environmental Conservation* 26(2): 125-135.

Lampitt, R.S., Fletcher, S., Cole, M., Kloker, A., Krause, S., O'Hara, F., Ryde, P., Saha, M., Voronkova, A., and Whyle, A. 2023. Stakeholder alliances are essential to reduce the scourge of plastic pollution.Nature Communications 14, 2849. https://doi.org/10.1038/s41467-023-38613-3.

National Conference of State Legislation.2020. State Beverage Container Deposit Laws. https://www.ncsl.org/environment-and-natural-resources/state-beverage-container-deposit-laws.

National Recycling Strategy, 2020.

Prata, J.C., A.L.P. Silva, J.P. Costa, C. Mouneyrac, T.R. Walker, A.C. Duarte, and T. Rocha-Santos. 2019. Solution and Integrated Strategies for the Control and Mitigation of Plastic and Microplastic Pollution. *International Journal of Environmental Research and Public Health* 16(13): 1-19.

Statista, 2023. Global plastic industry-statistics & facts. Available at https://www.statista.com/topics/5266/plastics-industry/#topicHeader wrapper. Accessed on January 20, 2023].

Syberg, K., F.R. Khan, H. Selck, A. Palmqvist, G.T. Banta, J. Daley, L. Sano, and M.B. Duhaime. 2015. "Microplastics: Addressing Ecological Risk Through Lessons Learned." *Environmental Toxicology and Chemistry* 34(5): 945–953.

Tejaswini, M.S.S.R., P. Pathak, S. Ramkrishna, and P.S. Ganesh. 2022. A Comprehensive Review on Integrative Approach for Sustainable Management of Plastic Waste and its Associated Externalities. *Science of Total Environment* 825(153973): 4-5.

The Recycling Partnership. 2016. "The 2016 State of Curbside Report." The recycling partnership. Available at: https://recyclingpartnership.org/wp. content/uploads/2018/05/state-of-recycling-report-Jan2017.pdf./[Accessed March 20, 2022].

United Nation Environment Program. 2022. Historic day in the campaign to beat plastic pollution: Nations commit to develop a legally binding agreement. Available at: Historic day in the campaign to beat plastic pollution: Nations commit to develop a legally binding agreement (unep.org)/[Accessed April 5, 2022].

Vaio, A.D., S. Hasan, R. Palladino, and R. Hassan. 2022. The Transition towards Circular Economy and Waste within Accounting and Accountability Models: a Systematic Review and Conceptual Framework. *Environment, Development and Sustainability*. Available at: https://doi.org/10.1007/s10668-021-02078-5 [Accessed September 25, 2022].

Wang, Y., and Yu, L. 2021. Can the current environmental tax rate promote green technology innovation? -Evidence from china's resource-based industries. Journal of cleaner production;278(123443):1-12. c

Weerdt, L.D., T. Compernolle, V. Hagspiel, P. Kort, and C. Oliveira. 2021. "Stepwise Investment in Circular Plastic under the Presence of Policy Uncertainty." *Environmental and Resource Economics* 83: 413-443.

Zhang, Y., and Buongiorno, J. 1998. " Paper or Plastic? The United States' demand for paper and paperboard in packaging." *Scandinavian Journal of Forest Research*.13: 54-65, 1998.

Greene, J. 2011. "Life cycle assessment of reusable and single-use plastic bags in California". In*stitute for Sustainable Development, California State University: Long Beach, CA, USA*, 1-26.

Table 1. List of different scenarios

Scenario	**Policy**
1. Scenario I: Two firms are independent	1. Tax on virgin plastic consumers with money back (TCMB) vs. tax on virgin plastic firms (TP)
2. Scenario II: Recycling and virgin plastic firms are connected	2. Tax on virgin plastic consumers with money back (TCMB) vs. tax on virgin plastic firms (TP)

Table 2. Assumption for estimation of demand and supply curve and welfare analysis in different policy scenarios

Virgin plastic market	Recycling plastic market
➢ Price of virgin plastic at benchmark scenario P_V=1620	➢ Price of recycled plastic at benchmark scenario P_R= σP_V(σ = 1.25)
➢ Quantity of virgin plastic supplied at benchmark scenario Q_V=22,674 (1,000 tons)	➢ Quantity of recycled plastic supplied at benchmark scenario Q_R= 1,973 (1,000 tons)
➢ Elasticity of demand of virgin plastic $(\varepsilon_{p,v}) = -1.22$	➢ Elasticity of demand of recycled plastic $(\varepsilon_{p,v}) = -1$
➢ Elasticity of supply of virgin plastic $(\varepsilon_{s,v}) = 1.22$	➢ Elasticity of supply of recycled plastic $(\varepsilon_{s,v}) = 1$
➢ Minimum supply price of virgin plastic	➢ Minimum supply price of recycled plastic
➢ $P_{min,v}$= γP_V =0.5*P_V	$P_{min,r}$= γ$P_{R=}$0.5*P_R
➢ Fraction of plastic that is return in TCMB γ=0.1	➢ Increase in supply of recycled plastic due to money back policy (Q_{MB})= ϕQ_V=0.2∗ Q_{MB}
➢ Money returned for consumers in TCMB= 3% of tax amount	➢ Total amount of CO2 emission (TCO2) in producing per kg of recycled plastic produced (Ψ) = = 0.54
➢ Tax amount =10%	
➢ Landfill Tip Cost (LTC)= $60.34 per ton	
➢ Total amount of CO2 emission (TCO2) in producing per kg of virgin plastic (Ψ) = 1.865	

Table 3: Consumer surplus (CS), producer surplus (PS), and government expenditure (GE), and government revenue (GR) in different policy scenarios

Scenario	Policy	CS		PS		GE	GR
		Virgin plastic market	Recycling plastic market	Virgin plastic market	Recycling plastic market	Virgin plastic market	Virgin plastic market
Benchmark scenario	No policy	CS_V^0=ΔAEP_v	CS_R^0=ΔKMP_R	PS_V^0= ΔBEP_v	PS_R^0= ΔMLP_R		
Scenario I	TCMB	CS_V^{MB}=ΔAK$P_{V,tc}$+ MB,	No change	PS_V^{MB}= ΔBI$P_{V,tP}$	No change	$Q_{MB} * P_{MB}$	$Q_{V,t}$* t
	TP	CS_V^{TF}=ΔAH'$P_{V,tc}$	No change	PS_V^{TF}= ΔI'B$P_{V,tp}$	No change		$Q'_{V,t}$* t
Scenario II	TCMB	CS_V^{MB}=ΔAK$P_{V,tc}$+ MB,	CS_R^{MB}=ΔKN$P_{R,mb}$	PS_V^{MB}= ΔBI$P_{V,tP}$	PS_R^{MB}= ΔKN$P_{R,mb}$	$Q_{MB} * P_{MB}$	$Q_{V,t}$* t
	TP	CS_V^{TF}=ΔAH'$P_{V,tc}$	CS_R^{TF}=ΔKN'$P_{R,tf}$	PS_V^{TF}= ΔI'B$P_{V,tP}$	PS_R^{TF}= ΔKN'$P_{R,tf}$		$Q'_{V,t}$* t

Notes: Benchmark scenario denotes the scenario of no policy intervention in the plastic market. Under Scenario I, the virgin plastic market and recycled plastic market are independent. However, under scenario II we assume that virgin plastic market and recycling plastic market are economically connected. Benchmark policy scenario, Scenario I, and Scenario II are presented in Figure 2, Figure 3, and Figure 4, respectively. MB in under Scenario II denotes the money back by returning Q_{MB} amount of used plastic in price P_{MB}.

Table 4 Landfill quantity in different scenarios

Scenario	Policy	Unrecycled plastic (Q_{UR})	Landfill plastic (Q_L)
Benchmark scenario	No policy	$Q_v - Q_R$	$Q_L = Q_V - Q_R - 0.163Q_V$
Scenario I	TCMB	$Q_{v,t} - Q_R$	$Q_L = Q_{v,t} - Q_R - 0.163Q_{V,t}$-$Q_{MB}$
	TP	$Q'_{V,t} - Q_R$	$Q_L = Q'_{V,t} - Q_R - 0.163Q'_{V,t}$
Scenario II	TCMB	$Q_{v,t} - (Q_R + \phi Q_{MB})$	$Q_L = Q_{v,t} - Q_R - 0.163Q_{v,t}$-$Q_{MB}$
	TP	$Q'_{V,t} - (Q_R - \phi Q_{MB})$	$Q_L = Q'_{V,t} - Q_R - 0.163Q'_{V,t}$

Notes**:** Benchmark scenario denotes the scenario of no policy intervention in the plastic market. In Scenario I, we assume virgin plastic market and recycled plastic market are independent. However, in scenario II we assume that virgin plastic market and recycling plastic market are economically connected. Benchmark policy scenario, Scenario I, and Scenario II are presented in Figure 2, Figure 3, and Figure 4, respectively.

Table 5 Consumer Surplus (CS), Producer Surplus (PS), government Revenue (GR), Government Expenditure (GE) Environmental Damage Cost (EDC), and Total Social Welfare (TSW) in different policy scenarios (in million)

Scenario	Policy	CS		PS		GR	GE	EDC	TSW $(CS+PS+GE-EDC)$	
		Virgin plastic market	Recycling plastic market	Virgin plastic market	Recycling plastic market	Virgin plastic market	Virgin plastic market	Virgin plastic market	Virgin plastic market	Recycling plastic market
Benchmark scenario	No policy	16725.05	2197.03	9182.97	998.65	0.00	0.00	56685.00	-30776.98	3195.67
Scenario I	TCMB	14093.47	2197.03	7091.32	998.65	5005.64	150.17	51498.32	-25458.07	3195.67
	TP	13943.30	2197.03	7091.32	998.65	5005.64	0.00	51498.32	-25458.07	3195.67
Scenario II	TCMB	14093.47	3160.13	7091.32	1207.22	5005.64	150.17	51498.32	-25458.07	4367.35
	TP	13943.30	1408.16	7091.32	790.08	5005.64	0.00	51498.32	-25458.07	2198.24

Notes**:** Benchmark scenario denotes the scenario of no policy intervention in the plastic market. In Scenario I, we assume virgin plastic market and recycled plastic market are independent. Furthermore, in scenario II we assume that virgin plastic market and recycling plastic market are economically connected. Benchmark policy scenario, Scenario I, and Scenario II are presented in Figure 2, Figure 3, and Figure 4 respectively. We assume 15% tax, 10% of used plastic being collected and 30% of the tax amount being returned. Additional recycling plastic produced compared to benchmark scenario under scenario II in TCMB policy is 0.2 times the returned quantity. Under TP, it is 0.2 times virgin plastic produced less than benchmark scenarios.

Table 6 Estimation of landfill quantity in different scenarios (in 1,000 tons)

Scenario	Policy	Virgin Plastic Produced	Recycled plastic Produced	Plastic combusted with energy recovery	Plastic returned due to money back policy	Landfill plastic ($Q_L = Q_V - Q_R - Q_E - Q_{MB}$)	Landfill plastic %	Recycling %
Benchmark scenario	No policy	22,674	1,973	3,696	-	17,006	75	8.70
Scenario I	TCMB	20,599	No change	3,358	2,060	13,209	64	9.58
	TP	20,599	No change	3,358	-	15,269	74	9.58
Scenario II	TCMB	20,599	2,385	3,358	2,060	12,797	62	11.58
	TP	20,599	1,561	3,358	-	15,681	76	7.58

Notes**:** Benchmark scenario denotes the scenario of no policy intervention in the plastic market. In Scenario I, we assume virgin plastic market and recycled plastic market are not connected to each other. Furthermore, in scenario II we assume that virgin plastic market affects the recycling plastic market. Benchmark policy scenario, scenario I, and scenario II are presented in figure 2, figure 3, and figure 4 respectively. Recycling % is calculated by Recycled plastic Produced ÷ Virgin plastic produced ×100. Furthermore, we assume 15% tax, 10% of used plastic being collected in collection center, and 30% of the tax amount being returned.

Table 7 Landfill Tip Cost (LTC), and CO2 emission

Scenario	Policy	Landfill Tip Cost (LTC) (in million)	TCO2 emission from virgin plastic market (in 1,000 metric ton)	TCO2 from recycled plastic market (in 1,000 metric ton)	TCO2 emission from plastic market (in 1,000 metric ton)
Benchmark scenario	No policy	1026.11	42287.01	1186.39	43473.40
Scenario I	TCMB	797.04	38417.75	1186.39	39604.14
	TP	921.33	38417.75	1186.39	39604.14
Scenario II	TCMB	772.18	38417.75	1706.47	40124.22
	TP	946.19	38417.75	760.41	39178.15

Notes**:** Benchmark scenario denotes the scenario of no policy intervention in the plastic market. In Scenario I, we assume virgin plastic market and recycled plastic market are not connected to each other. Furthermore, in scenario II we assume that virgin plastic market affects the recycling plastic market. Benchmark scenario, scenario I, and scenario II are presented in figure 2, figure 3, and figure 4, respectively. Landfill tip cost (LTC) is calculated by multiplying the quantity of landfill plastic in each policy scenario (Table 5) with per unit landfill tip cost which is $60.34 per ton in our estimation.

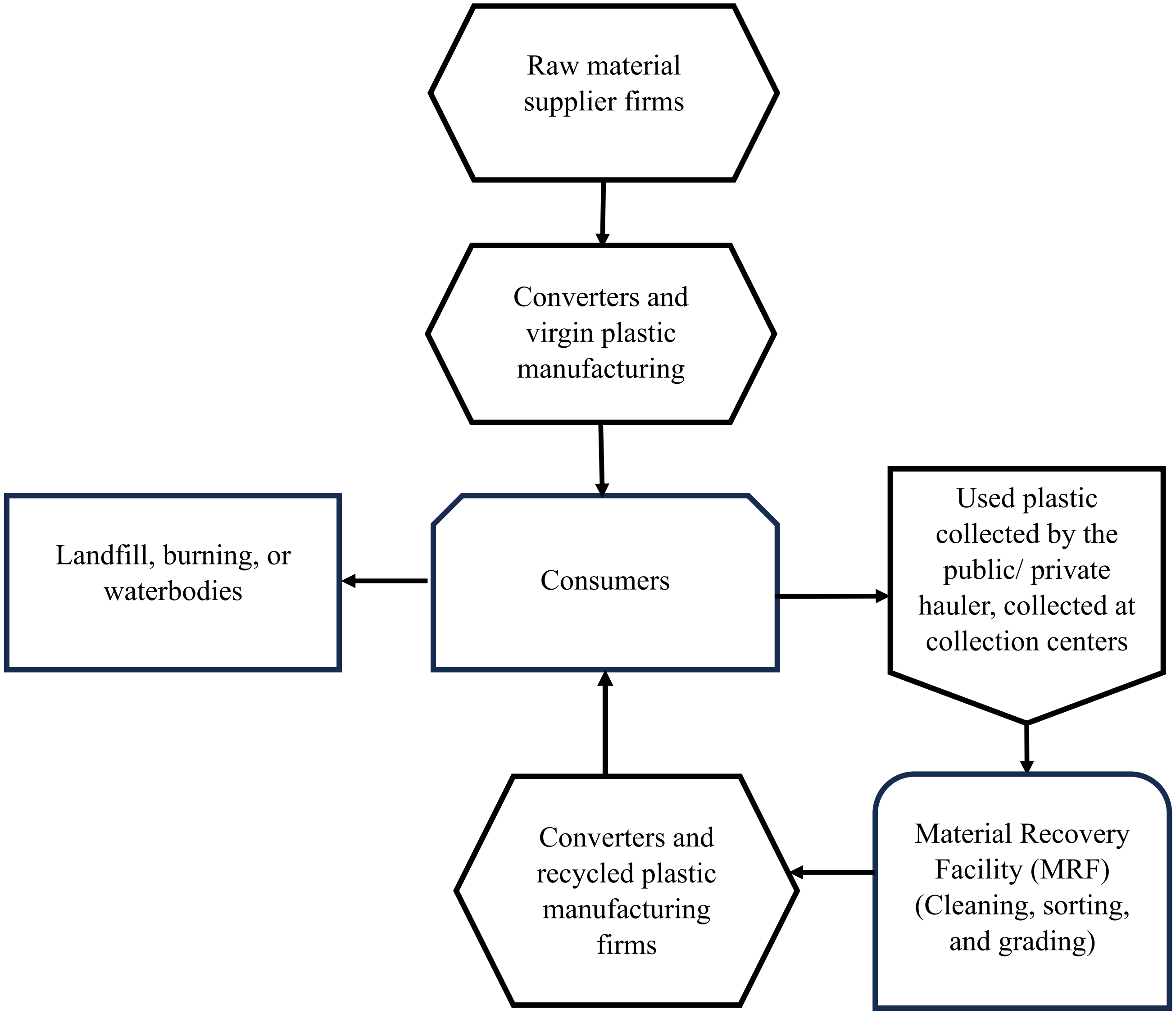

Figure 1. Flow chart of plastic and actors involved in the plastic market.

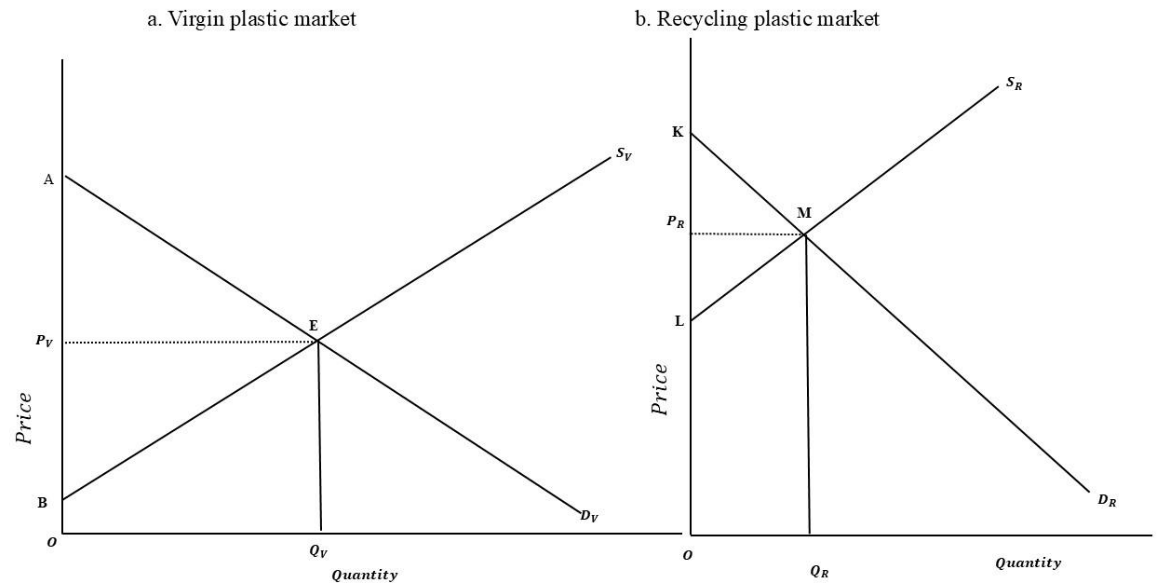

Figure 2. Benchmark scenario of virgin plastic market (a) and recycling plastic market (b). The unrecycled quantity of used plastic is $Q_V - Q_R$.

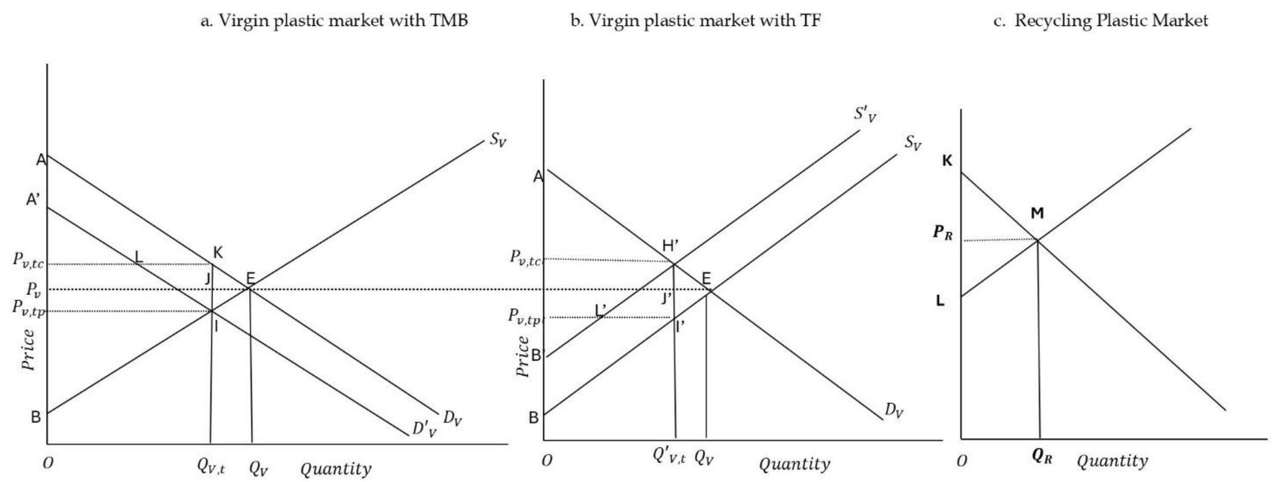

Figure 3. Effect of tax on virgin plastic consumers with money back (TCMB) (panel (a)) and tax on virgin plastic firms (TP) (panel (b)).
Notes: Under Scenario I, the CS and PS in recycling market is same as that of benchmark scenario because we assume that the policy on virgin plastic market does not affect recycled plastic market (i.e., virgin and recycled plastic market are not economically connected). The unrecycled plastic in TCMB is $Q_{V,t} - Q_R - Q_{MB}$, where Q_{MB} is the fraction of the used plastic returned for money back. However, the unrecycled plastic in TP is $Q'_{V,t} - Q_R$.

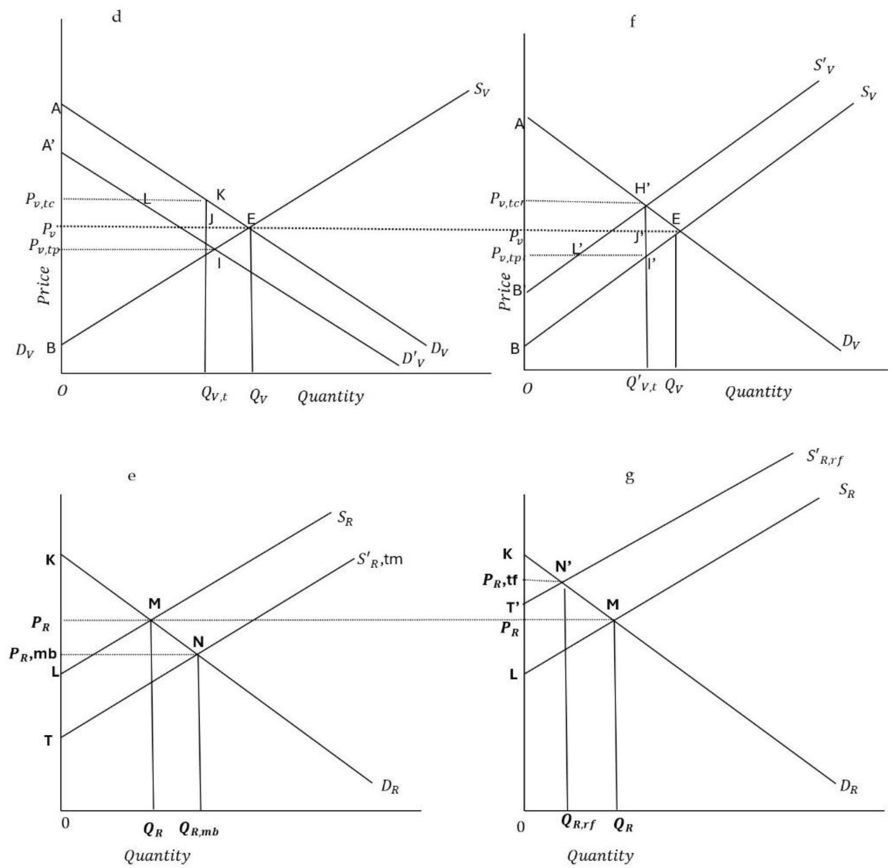

Figure 4. Effect of taxing virgin plastic consumers with money back (TCMB) policy (d) and this policy impact on recycling market (e). Similarly, the effect of tax on virgin plastic firms (TP) (f) and this TP policy impact on recycling firms (g).

Notes: The difference between figure 3 and figure 4 is that in Figure 3, the policy on virgin firms does not affect the recycling firm. However, in this figure 4, policy on virgin firms do impact on supply of recycling recycled plastic.

Appendix

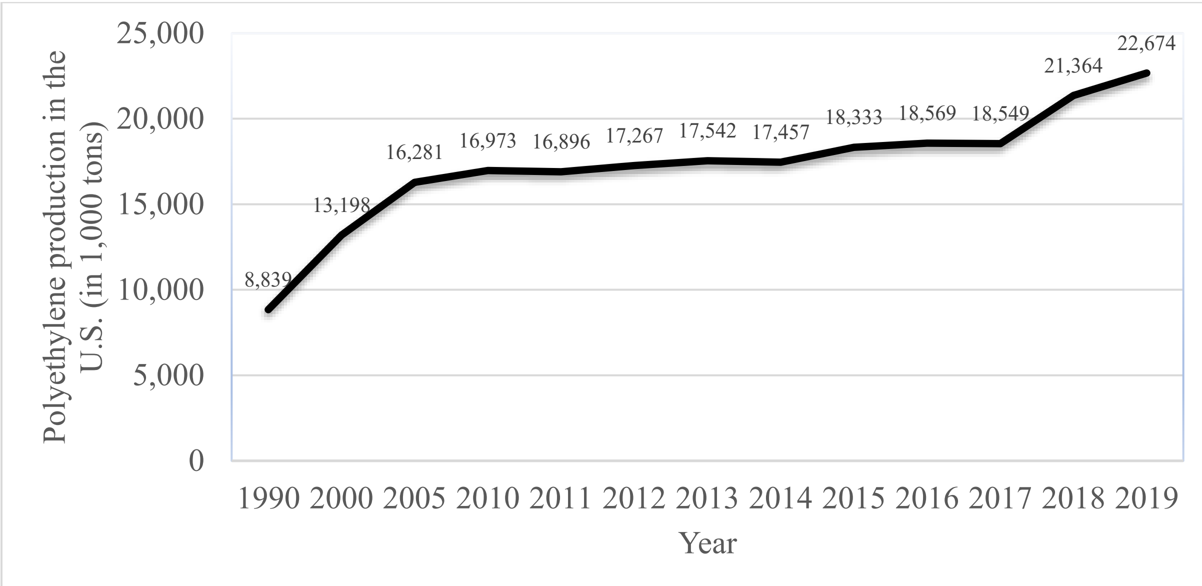

Figure S1. Polyethylene production in the U.S. (in 1,000 tons).
Source: https://www.statista.com/statistics/975591/us-polyethylene-production-volume/.
Published by Madhumitha Jaganmohan on Jan 10, 2024. Accessed on December 23, 2024.
Which derives this information from: United States; American Chemistry Council; US Census Bureau; US International Trade Commission; ICIS; IHS; FEB; AFPM; TFI; Various sources (Chlorine Institute, Rubber Manufacturers Association); 1990 to 2019:

Supplementary Table 2 Price of different types of plastic polymers

Types of plastic	US $/pound	US$/metic ton
HDPE blow molding	0.74	1631.4188
HDPE Injection	0.65	1433.003
HMWPE FILM	0.67	1477.0954
LDPE FILM	0.73	1609.3726
LDPE INJECTION	0.87	1918.0194
LLDPE FILM	0.72	1587.3264
LLDPE INJECTION	0.72	1587.3264
PP COPOLYMER INJECTION	0.78	1719.6036
Average price	0.735	1620.3957

Source: https://www.recycleinme.com/plasticpricelisting/US%20Plastic%20Prices.
Note: In our analysis we used the average price. Updated October 24, 2024. Accessed on December 24, 2024.

Effect of tax

a. Tax on virgin plastic producing firm

Let P_v^* is the price that consumer pay for virgin plastic and $P_v^* - t$ is the price that virgin plastic firms receive. If Q_v^* is the equilibrium quantity in the market, then in equilibrium,

D (P_v^*) -Q_v^*= 0

S $(P_v^* - t)$ - Q_v^*= 0

Differentiating above two equations with respect to 't' yields,

$$D_{pv}.\frac{\partial P_v^*}{\partial t} - \frac{\partial Q_v^*}{\partial t} = 0 \quad \text{(i)}$$

$$S_{pv}.\frac{\partial P_v^*}{\partial t} - S_{p,v} - \frac{\partial Q_v^*}{\partial t} = 0$$

$$\text{or } S_{pv}.\frac{\partial P_v^*}{\partial t} - \frac{\partial Q_v^*}{\partial t} = S_{pv} \quad \text{(ii)}$$

To utilize the Cramer's rule, writing above equation in matrix notation

$$\begin{bmatrix} \mathrm{D_{pv}} & -1 \\ \mathrm{S_{pv}} & -1 \end{bmatrix} \begin{pmatrix} \frac{\partial \mathrm{P_v^*}}{\partial \mathrm{t}} \\ \frac{\partial \mathrm{Q_v^*}}{\partial \mathrm{t}} \end{pmatrix} = \begin{pmatrix} 0 \\ \mathrm{S_{pv}} \end{pmatrix}$$

For change in price due to tax,

$$\frac{\partial P_v^*}{\partial t} = \frac{\begin{bmatrix} 0 & -1 \\ \mathrm{S_{pv}} & -1 \end{bmatrix}}{\begin{bmatrix} \mathrm{D_{pv}} & -1 \\ \mathrm{S_{pv}} & -1 \end{bmatrix}} = \frac{\mathrm{S_{pv}}}{\mathrm{S_{pv}} - \mathrm{D_{pv}}} = \frac{\mathrm{S_{pv}}}{\mathrm{S_{pv}} - \mathrm{D_{pv}}} * \frac{P_v^*/Q_v^*}{P_v^*/Q_v^*} = \frac{e_{S,pv}}{e_{S,pv} + |e_{D,pv}|} \quad , \quad \text{(iii)}$$

where $e_{S,pv}$ and $e_{D,pv}$ denotes the supply and demand price elasticity of virgin plastic respectively.

Therefore, the new price paid by the consumer $P_{v,t}^*$ after tax t is given by,

$$P_{v,tc}^* = P_v^* + \frac{e_{S,pv}}{e_{s,pv} + |e_{D,pv}|} * t \quad \text{(iv)}$$

For change in quantity due to per unit tax,

$$\frac{\partial Q_v^*}{\partial t} = \frac{\begin{bmatrix} \mathrm{D_{pv}} & 0 \\ \mathrm{S_{pv}} & \mathrm{S_{pv}} \end{bmatrix}}{\begin{bmatrix} \mathrm{D_{pv}} & -1 \\ \mathrm{S_{pv}} & -1 \end{bmatrix}} = \frac{\mathrm{D_{pv}}\,\mathrm{S_{pv}}}{\mathrm{S_{pv}} - \mathrm{D_{pv}}} = \mathrm{D_{pv}}.\frac{\partial P_v^*}{\partial t} * \frac{P_v^*/Q_v^*}{P_v^*/Q_v^*} = \frac{e_{S,pv}\,e_{D,pv}}{e_{S,pv} + |e_{D,pv}|} * \frac{Q_v^*}{P_v^*}$$

Therefore, the quantity demanded after tax t:

$$Q^*_{v,t} = Q^*_v - \frac{e_{S,pv}\, e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * \frac{Q^*_v}{P^*_v} * t \quad \text{(v)}$$

Dead weight loss,

The size of the deadweight loss can be estimated by the area of the triangle (called as Herberger's triangle) whose base is given by the amount of tax t and height is given by the reduction in quantity due to tax. The deadweight (DW) loss will be,

$$DW = 0.5t * \frac{\partial Q^*_v}{\partial t} * t = 0.5 * \frac{\partial Q^*_v}{\partial t} * t^2 = 0.5 * \frac{e_{S,pv}\, e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * \frac{Q^*_v}{P^*_v} * t^2 = 0.5 * \left(\frac{t}{P^*_v}\right)^2 \frac{e_{S,pv}\, e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * Q^*_v\, P^*_v$$

The above equations (iv and v) show the effect of tax on virgin plastic producing firms. In case of plastic market $e_{S,pd} > 0$ and $e_{S,pd} < 0$, imposition of tax will increase the price paid by the consumers. Since $e_{S,pd} > 0$ consumers will have some burden of tax[13].

b. Tax on consumers

Let P^*_v is the price received by seller and $P^*_v + t$ is the price that consumer pay after tax. Let Q^*_v is the equilibrium output in the market, then in equilibrium:

$D\,(P^*_v + t) - Q^*_v = 0$

$S\,(P^*_v) - Q^*_v = 0$

Differentiating above demand and supply equation with respect to tax t yields,

$$D_{pv}.\frac{\partial P^*_v}{\partial t} + D_{pv} - \frac{\partial Q^*_v}{\partial t} = 0$$

$$D_{pv}.\frac{\partial P^*_v}{\partial t} - \frac{\partial Q^*_v}{\partial t} = -D_{pv} \quad \text{(vi)}$$

$$S_{pv}.\frac{\partial P^*_v}{\partial t} - \frac{\partial Q^*_v}{\partial t} = 0 \quad \text{(vii)}$$

To utilize the Cramer's rule, writing above equation in matrix notation,

$$\begin{bmatrix} D_{pv} & -1 \\ S_{pv} & -1 \end{bmatrix} \begin{pmatrix} \frac{\partial P^*_v}{\partial t} \\ \frac{\partial Q^*_v}{\partial t} \end{pmatrix} = \begin{pmatrix} -D_{pv} \\ 0 \end{pmatrix}$$

Using Cramer's rule, change in price P^*_v due to tax t,

[13] If plastic market would be the case where $e_{S,pd} = 0$, the price would not rise.

$$\frac{\partial P_v^*}{\partial t} = \frac{\begin{bmatrix} -\mathrm{D_{pv}} & -1 \\ 0 & -1 \end{bmatrix}}{\begin{bmatrix} \mathrm{D_{pv}} & -1 \\ \mathrm{S_{pv}} & -1 \end{bmatrix}} = \frac{\mathrm{D_{pv}}}{-\mathrm{D_{pv}}+\mathrm{S_{pv}}} = \frac{\mathrm{D_{pv}}}{\mathrm{S_{pv}}-\mathrm{D_{pv}}} * \frac{P_v^*/Q_v^*}{P_v^*/Q_v^*} = \frac{e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} \quad \text{(viii)}$$

Price received by sellers,

$$P_{v,tp}^* = P_v^* - \frac{e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * t$$

Price paid by consumers,

$$P_{v,tc}^* = P_{v,tp}^* + t \quad \text{(ix)}$$

Change in quantity,

$$\frac{\partial Q_v^*}{\partial t} = \frac{\begin{bmatrix} \mathrm{D_{pv}} & -\mathrm{D_{pv}} \\ \mathrm{S_{pv}} & 0 \end{bmatrix}}{\begin{bmatrix} \mathrm{D_{pv}} & -1 \\ \mathrm{S_{pv}} & -1 \end{bmatrix}} = \frac{\mathrm{D_{pv}}\,\mathrm{S_{pv}}}{\mathrm{S_{pv}}-\mathrm{D_{pv}}} = \mathrm{D_{pv}}.\frac{\partial P_v^*}{\partial t} * \frac{P_v^*/Q_v^*}{P_v^*/Q_v^*} = \frac{e_{S,pv}\,e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * \frac{Q_v^*}{P_v^*}$$

New quantity under taxing consumers:

$$Q_{v,t}^* = Q_v^* - \frac{e_{S,pv}\,e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * \frac{Q_v^*}{P_v^*} * t$$

The deadweight loss calculation will be the same.

$$\mathrm{DW} = 0.5t * \frac{\partial Q_v^*}{\partial t} * t = 0.5 * \frac{\partial Q_v^*}{\partial t} * t^2 = 0.5 * \frac{e_{S,pv}\,e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * \frac{Q_v^*}{P_v^*} * t^2 = 0.5 * \left(\frac{t}{P_v^*}\right)^2 \frac{e_{S,pv}\,e_{D,pv}}{e_{S,pv}+|e_{D,pv}|} * Q_v^*\,P_v^*$$