If you build it, they will compost: The effects of municipal composting services on household waste disposal and landfill emissions

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Abstract

Landfills are the third largest source of human-related methane emissions. Composting food waste generates significantly less methane emissions than landfills, yet the majority of food waste is sent to landfills. This paper examines how local government provision of composting services effects the amount of household waste going to landfills. Specifically, we examine the quasi-random adoption of Food Organics and Garden Organics (FOGO) curbside collection services by local councils in New South Wales, Australia—a service that aims to reduce landfill waste by making composting more convenient. Using council-level waste disposal data from 2008–2015 and an event study design, we find that FOGO adoption diverted 4.5 kg of waste per household per week from the landfill stream into the composting stream, one-third of the waste the average household was sending to landfill prior to FOGO adoption. We find no evidence that FOGO adoption altered the total amount of household waste disposed and little to no evidence of spillovers on dry-recycling waste. Back-of-the-envelope calculations reveal that FOGO adoption could divert 718,936 tonnes of waste in New South Wales landfills per year and reduce greenhouse gas emissions from landfills by 6-28%.

Keywords: food and garden waste; curbside waste collection; composting; recycling; landfills, methane emissions; event study

1 Introduction

Methane (CH_4) is a powerful greenhouse gas 28-34 times more effective than carbon dioxide (CO_2) at trapping heat in the atmosphere over a 100-year period (Myhre et al., 2013). Given methane remains in the atmosphere for a much shorter amount of time than carbon dioxide (US EPA, 2021a), reductions in methane emissions today have a more immediate impact on reducing global warming. Moreover, global methane mitigation models find "reducing human-caused methane emissions is one of the most cost-effective strategies to rapidly reduce the rate of warming" (UNEP and CCAC, 2021). Landfills provide a key avenue for reducing methane emissions. Landfills are the third largest source of human-related methane emissions, after fossil fuels and livestock (US EPA, 2021a; UNEP and CCAC, 2021), with methane comprising 50-55% of landfill gas by volume (ATSDR, 2008). Landfills produce methane though anaerobic decomposition—the lack of oxygen in landfills allows anaerobic microbes to decompose organic waste into methane (ATSDR, 2008).

Alternatively, composting organic waste generates significantly less methane than landfills because composting is an aerobic process (oxygen is introduced either by turning the waste or through the use of worms and other living organisms) and methane-producing microbes are not active in the presence of oxygen (US EPA, 2021b; Lou and Nair, 2009). With respect to cost-effectiveness, composting organic waste is among the low-cost measures for reducing methane emissions from landfills (UNEP and CCAC, 2021).[1] In addition to reducing greenhouse gas emissions, recycling organic waste into compost is higher than landfill on the Environmental Protection Agency's (EPA) waste

[1]Other low-cost options for reducing methane emissions from landfills are gas capture for direct use, gas capture for use in electricity generation, and flaring of landfill gas, whereas waste to energy and mechanical biological treatment are above the low cost threshold (UNEP and CCAC, 2021).

disposal hierarchy because compost reduces the need for chemical fertilizers, promotes higher yields in agricultural crops, aids reforestation, wetland restoration and habitat revitalization, enhances water retention in soils, and provides carbon sequestration (US EPA, 2021b).[2]

Despite the benefits of composting, the majority of food waste in many countries is send to landfills or is incinerated.[3] This is particularly concerning given the amount of food that is wasted—the Food and Agriculture Organization (FAO, 2021) estimates that 1.3 billion tonnes of food produced for human consumption is lost or wasted globally each year, one-third of the total produced. To address the problems of landfills and encourage circular economies, governments around the world are increasingly investing in municipal composting services. In the European Union the amount of municipal waste that was composted increased from 11% in 2004 to 17% in 2018 (van der Linden and Reichel, 2020), in the US the number of municipalities with separate food waste collection increased from 24 in 2005 to 198 in 2013 (Yepsen, 2015), and in Australia the share of local governments offering composting collection for food and garden waste increased from 10% in 2012 to 16% in 2018 (Hyder Consulting, 2012; Pickin et al., 2018).

Given the growing supply of municipal composting services for food waste, this paper examines household demand for and use of composting services. Specifically, we ask: (1) How does local government provision of curbside composting services affect the amount of household waste going to landfills? (2) Are there spillover effects of

[2]It is important to note that, while not the focus of this paper, the most preferable option in the waste disposal hierarchy is to avoid and reduce the amount of waste generated (US EPA, 2021b). Strategies for reducing food loss and waste include improving inventory systems, improving the cold-storage food chain, reducing portion sizes, and correctly interpreting label dates (UNEP and CCAC, 2021).

[3]For instance, in the US 56% of food waste is sent to landfills, 12% is incinerated, 28% is sent to other food management pathways, and 4% is composted (US EPA, 2020).

composting services on total household waste disposal and on other streams of waste disposal, namely dry recycling? and (3) How much are greenhouse gas emissions reduced by adopting composting services?

The motivation behind curbside composting services is to reduce landfill waste by making composting more convenient, in line with the general principle that policies that lower the cost of recycling can encourage recycling (Ando and Gosselin, 2005). Without curbside compost collection, household food waste is most likely sent to landfill unless households individually take the initiative to backyard compost or to collect and drop off their food waste at a community compost center. Thus, this paper seeks to measure how the addition of more convenient municipal composting services influences households' waste disposal behavior.

We estimate the causal relationship of curbside compost collection on the amount of household waste that is redirected from landfill to composting by exploiting a large-scale quasi-experiment in New South Wales (NSW), the most populous state in Australia. Starting in 2010, local governments in NSW (i.e., councils) began adopting Food Organics and Garden Organics (FOGO)—a curbside collection service that allows food and garden organic waste to be recycled into compost. By 2015, 30 councils had adopted FOGO, covering 16% of the state's population. This variation in policy adoption by location over time enables us to separate the impact of the FOGO policy from other time-varying council-level factors that may impact waste disposal. Using this temporal and spatial variation, we estimate event study models to compare outcomes in treated councils (FOGO adopters) to control councils (non-adopters).[4]

[4]We estimate our event study regression models using both OLS with two-way fixed-effects as well as new event-study estimators that correct for potential biases (Goodman-Bacon, 2021; Callaway and Sant'Anna, 2020; de Chaisemartin and D'Haultfœuille, 2020; Baker et al., 2021; Borusyak et al., 2021; Sun and Abraham, 2021).

Our measures of household waste by waste stream come from the annual *NSW Local Government Waste and Resource Recovery* (WARR) reports (NSW EPA, 2021). Using the WARR reports from 2008 to 2015, we construct a balanced sample of 138 councils. The outcome variables of interest are the average weight (kg) of waste per household week, by bin type. All NSW councils provide residents with a red bin for general curbside waste collection to be sent to landfill. The majority also provide residents with a yellow bin for dry recyclables (e.g., hard plastics, bottles, mixed paper, newspaper, and cardboard). Some also provide a green bin for garden waste (e.g., lawn clippings, twigs, and leaves). After FOGO adoption, households can put both food and garden waste in the green bin, which is sent to organic waste composting facilities.[5]

Using an event study design, we first estimate how FOGO adoption affects the amount of household waste collected in the red (landfill) and green (composting) bins. Second, we examine if FOGO adoption has spillover effects on the amount of waste going to yellow (dry recycling) bins. We hypothesize that the effect of FOGO on dry recycling could go either direction. On one hand, households may experience complimentarities in sorting dry recyclable waste from their food waste contents which makes dry recycling easier under FOGO. On the other hand, the time costs of additionally sorting FOGO waste may crowd out sorting dry recycling from landfill. Third, we examine if FOGO adoption influences the total amount of curbside waste collected. If households have pent-up demand for waste disposal, the addition of a new bin may lead to an increase in total waste disposal. Finally, we use back-of-the-envelope calculations to estimate the effects of FOGO adoption on greenhouse gas emissions from landfills.

[5]These facilities use various composting technologies. The most common method in Australian facilities is windrowing, whereby organic matter is placed in rows and turned at regular intervals as it decomposes. The center of the piles are required to reach more than 55°C for three consecutive days prior to turning so that the compost is thoroughly pasteurised. Once processed, the nutrient-rich compost is sold on the market (Hyder Consulting, 2012).

Our results show that curbside collection of food waste via the FOGO bin gives households increased capacity to conveniently compost their food waste. Specifically, we find that on average households redirect 4.5 kg of organic waste per week from the landfill stream into the FOGO stream. This is an economically significant substitution effect as it represents approximately one-third of the waste households were sending to landfill prior to FOGO adoption. With respect to dry recycling, the results show that FOGO has little net impact on the amount of dry recycling households generate. If anything, there is evidence of a small and only marginally significant crowding out effect. Back-of-the-envelope calculations reveal that statewide FOGO adoption could divert approximately 718,936 tonnes of organic waste from NSW landfills per year, reducing landfill emissions by 6-28%.

This paper contributes to the literature surrounding the determinants of household waste management. These determinants can be separated into three categories: external influences (demographic and socioeconomic variables); internal influences (attitudes, norms, and beliefs); and features of the waste collection system (cost and convenience) (Saphores and Nixon, 2014). The addition of the FOGO bin changes the relative cost and convenience of the existing service, thus falling into the third category (a change in the features of the system). Several studies have found that increasing the relative cost of one waste stream increases the amount of waste generated in the other (Jenkins, 1993; Miranda et al., 1994; Fullerton and Kinnaman, 1996; Palmer et al., 1997; Choe and Fraser, 1998; Miranda and Aldy, 1998; Nestor and Podolsky, 1998; Kinnaman and Fullerton, 2000; Dijkgraaf and Gradus, 2004).[6] However, most of these studies focus on either curbside dry recycling programs or the effects of unit-pricing systems. For example, Fullerton and Kinnaman (1996) find that increasing the per-unit cost of land-

[6]See Kinnaman (2017) for a review of this literature.

fill waste reduced the weight of landfill waste by 14% and increased the weight of dry recycling by 16%.

Beyond the monetary cost, the relative convenience of waste services can also create a substitution effect. Convenience strongly incentivizes whether households use a particular waste stream (Ando and Gosselin, 2005). For example, more frequent curbside collections have been found to increase dry-recycling as it reduces the time cost of holding waste (Jenkins et al., 2003; Kuo and Perrings, 2010). Other factors that can influence convenience include storage space and ease of use (Miafodzyeva and Brandt, 2013). Since dry recycling policies have historically been more prevalent, they tend to be the focus of these studies. We extend the literature by examining how the convenience of a third stream for organic waste collection impacts household waste decisions.

Nevertheless, there is a small existing body of work focusing on curbside organic waste collection services. These studies generally find organic waste collection services to be successful in diverting waste away from landfill, especially in urban areas (Sterner and Bartelings, 1999; Curtis et al., 2010; Gellynck et al., 2011). In fact, Gellynck et al. (2011) find that having a curbside organic service has a stronger impact on minimising household landfill waste than frequency of collection, yearly cost of curbside waste collection, and average income per capita. However, these studies use either cross-sectional waste collection data, which cannot control for the effect of unobserved area characteristics, or data from only one jurisdiction, which cannot control for the unobserved effects over time. Hence, this paper adds to the organic-composting literature by estimating the causal effect of such a policy using administrative panel data and an event study design.

Finally, this study also contributes to the research surrounding the spillover effects of pro-environment behaviors. Spillovers arise when one pro-environmental behavior affects the propensity a person commits another pro-environmental behavior, such as how sorting food waste affects the propensity to sort dry recycling waste. The literature is mixed as to whether these spillovers are positive or negative (Thøgersen, 1999; Thøgersen and Ölander, 2003; Whitmarsh and O'Neill, 2010; Barr et al., 2010; Weber, 1997; Sintov et al., 2019). Focusing on the spillovers between food composting and dry recycling behaviors specifically, Ek and Miliute-Plepiene (2018) and Alacevich et al. (2021) both find positive spillovers of food-waste collection on dry-recyclable collection in Sweden. While our studies are similar in methods, we find, if anything, a negative spillover effect on dry-recycling, which suggests spillover effects may be context specific.

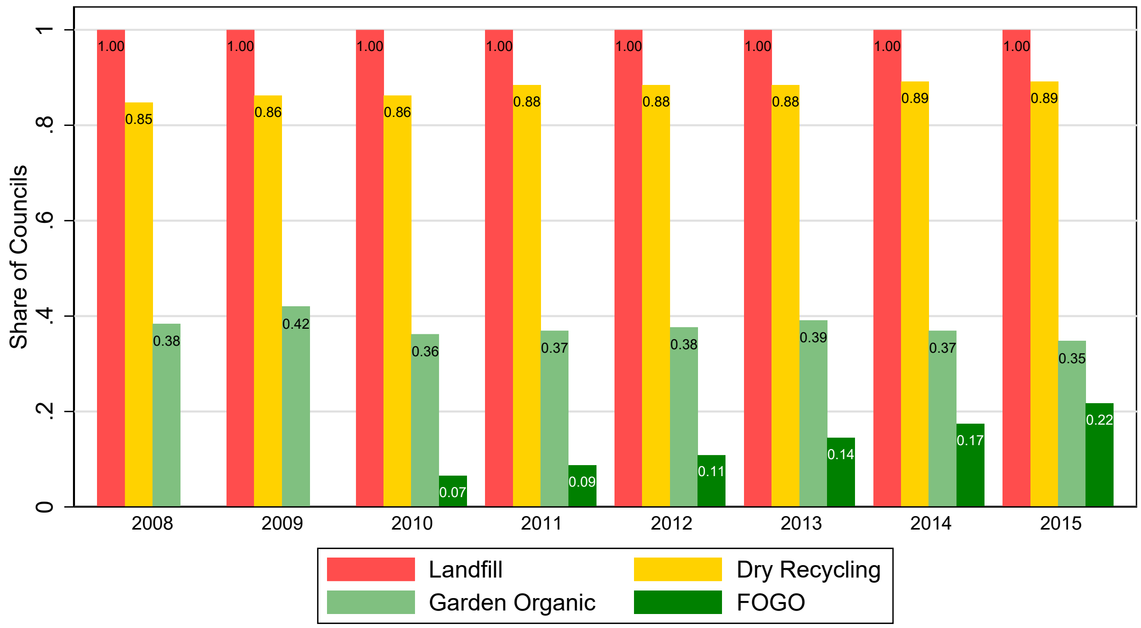
The remainder of this paper is structured as follows. Section 2 describes the FOGO program and provides summary statistics for the waste and recovery data. Section 3 details the event study empirical methodology. Section 4 reports the main results for how curbside composting services affect household waste disposal, by waste stream, and section 5 translates the results into emission reductions. Finally, section 6 establishes how the results can be of use to those designing waste policies.

2 Data

2.1 Background on Food Organics and Garden Organics

With variation in adoption across time and space, NSW provides a quasi-experiment for analyzing the effects of curbside compost collection. From 2010 to 2015, 30 councils adopted Food Organics and Garden Organics (FOGO) programs, affecting 16% of the state's population. Curbside waste-management services in NSW are managed at the local council level. Councils individually decide whether or not to provide FOGO col-

Figure 1: FOGO adoption over time



Note: This figure plots the share of councils providing curbside pickup for landfill, dry recycling, garden organic, and FOGO waste.

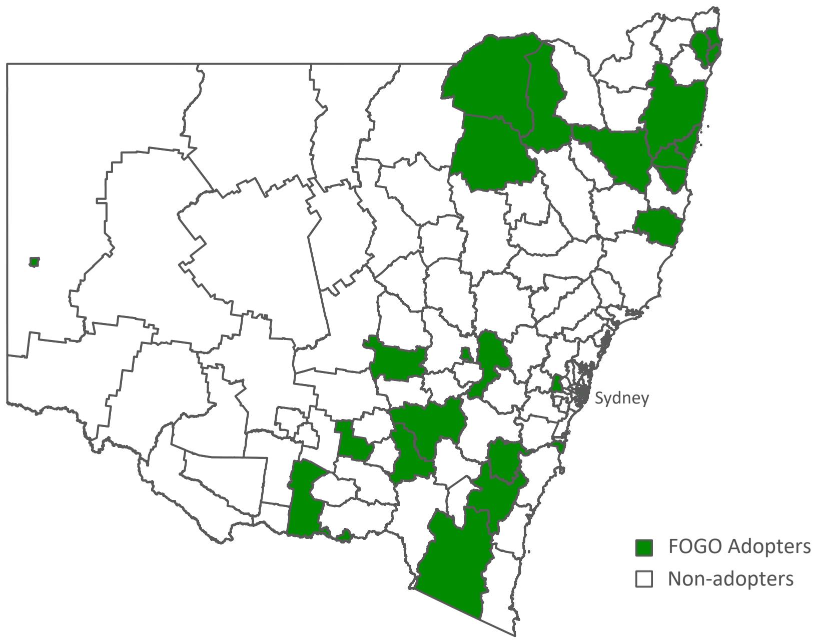
lection to their residents.[7] Prior to FOGO, councils offered a combinations of curbside bins for landfill (red bins), dry recycling (yellow bins), and garden waste (green bins). FOGO adoption allows both food and garden waste to be put in the green bin.[8]

Figure 1 presents the share of councils from 2008 to 2015 offering curbside collections for landfill, dry recyclables, garden waste, and FOGO. All 138 councils in our sample offer landfill collection (red) throughout the sample period. Dry recycling collection (yellow) is offered by 85% of councils in 2008 and increases slightly to 89% by 2015. Garden waste collection (light green) is offered by 38% of councils in 2008 and fluctuates

[7]Councils can partially offset the costs of adopting FOGO by applying for competitive grants from the NSW EPA for developing organics collection infrastructure. As of 2021, there have been 8 rounds of grants funding 65 projects (source: NSW EPA, Grants, Online).

[8]FOGO can be adopted by councils regardless of whether they have a garden waste service currently in place (NSW EPA, 2021).

Figure 2: FOGO Adoption in NSW by 2015



Note: This figure depicts adoption of FOGO by NSW councils as of 2015, the last year of our sample. FOGO adoption began in 2010. Councils without FOGO are unshaded. Councils with a FOGO are shaded in green.

over time to 35% in 2015, as some councils adopt it while other councils replace it with FOGO. Finally, the share of councils with FOGO collection (dark green) increases from 0% in 2008 to 22% in 2015. While FOGO adoption is the main interest and source of variation in this paper, our regression models will additionally control for the smaller changes that occur in dry recycling and garden organic collection.

Given FOGO adoption is a non-random council level decision, it is important to analyse whether there are systematic differences between early-adopting, late-adopting and non-adopting councils. To understand the spatial variation of FOGO adoption, Figure 2 depicts the councils that have adopted FOGO by 2015, the end of our sample period. We see that adoption occurs primarily in the eastern coastal half of the state, which is more populated than the western division.[9] To further examine differences in characteristics between treated and control councils, Figure 3 plots councils by their FOGO implementation year (x-axis) against four key council-level characteristics (y-axis): a) mean income per capita, b) population density, c) vote share for the conservative Liberal/National Party and d) share of the population with a post-secondary education. The size of the circle reflects the councils relative population size.

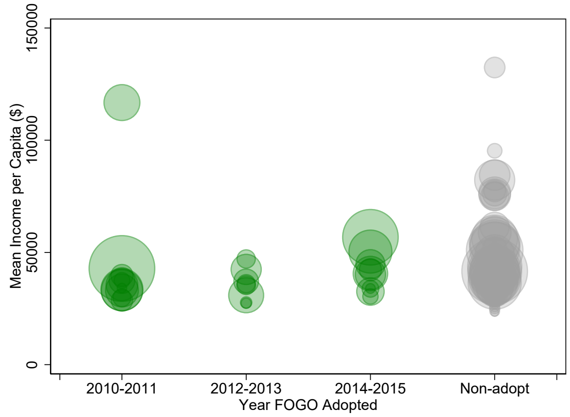
These variables were chosen given their potential to motivate household waste-disposal decisions. For instance, households with a higher mean income may have higher time costs of separating waste than lower-income households (Beatty et al., 2007). Households in areas of higher population density may have less space to sort waste than those in less dense areas (Ando and Gosselin, 2005). Households that vote for the conservative Liberal/National Party may be less enthusiastic about recycling and composting programs than their left-leaning peers (Taylor, 2019), and households with higher educations may have more knowledge of the benefits of composting waste (Sidique et al., 2010). Given these variables can impact household waste-disposal behavior, it is useful to establish whether there are any noticeable differences in them among early, late, and never-adopters.

The relatively similar distributions in panels (a), (c), and (d) suggest that the early, late and never-adopters do not vary greatly with respect to income, political leaning, or education. Panel (b), however, suggests that FOGO is more prevalent among jurisdictions with lower population density. While there is substantial variation in population density among never-adopters, the adopters tend to have population density below 1000 people per square kilometer. This is explained by the fact that the

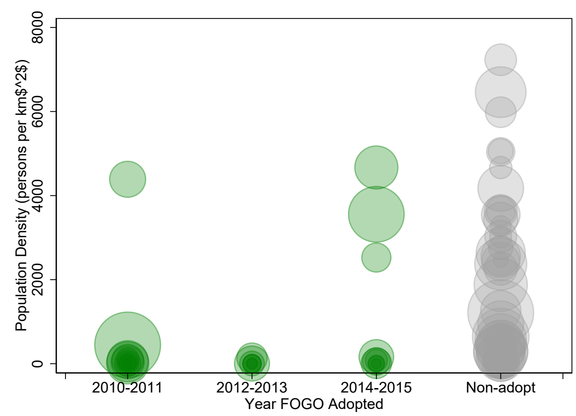
[9] Roughly 85% of Australians live within 50km of the coast (source: Australian Bureau of Statistics, Year Book Australia, 2014, Online.

Figure 3: Council characteristics by implementation year and population size

(a) Mean Income Per Capita (AU$)

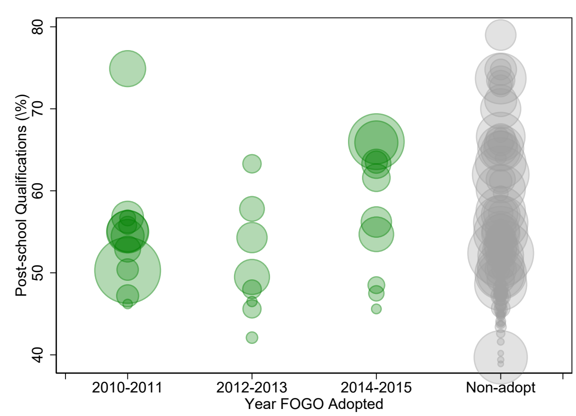


(b) Population Density (persons per km^2)



(c) Vote Share for the Liberal/National Party

(d) Share with Post-secondary Education



Note: Panels plots councils by year of FOGO adoption against the following council-level variables: (a) mean income per capita (2008); (b) population density (2008); (c) share of vote for the Liberal/National Party (2011 NSW election) and (d) share of population with post-secondary qualifications (2008). The gray circles represent the non-adopting councils. The green circles represent the FOGO adopting councils. The size of the circle reflects the council's population size.

35 councils within the Greater Sydney area are the most dense on average, yet only four councils within this region adopted FOGO between 2010 and 2015. Yet even if there is a systematic difference in the population density between the adopters and non-adopters, event study and difference-in-differences designs can still produce unbiased estimates. This is conditional on their being parallel trends in the outcome variables between the

treated and control group in the pre-policy period. As explained further in section 3, we will test this key identifying assumption of our empirical design.

2.2 Waste and Resource Recovery Report Data

To measure the effect of FOGO adoption on household waste disposal, we obtained data from the *NSW Local Government Waste and Resource Recovery* (WARR) reports (NSW EPA, 2021), which are maintained by the NSW EPA and detail the specific curbside services provided in a council, as well as the weight of waste collected from each different curbside service (red, yellow, and green bins) per year. The NSW EPA additionally calculates the average amount of waste per household-week in a council by dividing the waste totals for each council-year by the number of households in a council and weeks in the year. In NSW, for the most part, households in a council are automatically subscribed to a waste management service rather than having individual autonomy to choose a certain version of the curbside service.

Using the WARR reports from 2008 to 2015, we construct a balanced sample of 138 councils.[10] The main outcome variables of interest are the average amount of waste per household per week collected from green bins (organic waste), red bins (landfill waste), and yellow bins (dry-recycling waste). The WARR reports additionally provide information on a range of waste-related and demographic characteristics, such as the frequency of each waste service provided, the size of each bin, total annual-waste management charges, population, and number of individual households. We merged this data with council-level mean income per capita and population density, which are collected annually by the Australian Bureau of Statistics.

Finally, some councils have an Alternative Waste Treatment (AWT) service which

[10]We drop 14 councils due to missing waste data in order to maintain a balanced panel.

diverts a portion of the waste from the red bin. The AWT service is implemented at the council-level and involves recycling waste from the red bin to produce fuel or biogas. The WARR reports detail which councils have the service in a given year, with 20 councils using it in 2015. Unlike FOGO, which directly impacts the way households separate waste, AWT is conducted post-collection. It is unclear to what extent households within a council are aware as to whether AWT is being used. However, given it is possible that households alter their waste disposal behaviors in response to AWT, we will control for AWT services in our regression models.

2.3 Summary Statistics for Treated and Control Councils

For the purpose of this study, the treated councils are the 30 councils that adopt FOGO at some point between 2010 and 2015 and the control councils are the 108 councils that do not. In Tables 1 and 2 we compare the waste-related and demographic variables between the treated and control councils using data from 2008, which is a pre-treatment year for all councils.

Table 1 shows that total curbside waste for both treated and control councils is approximately 20 kg per household per week, two-thirds of which comes from red bin landfill waste. The amount of organic waste and dry recycling waste is slightly higher for treated councils, but the difference is only statistically significant for dry recycling. This reflects the fact that those that adopt FOGO bins were also more likely to have curbside dry recycling bins. Additionally we find that both treated and control councils charge AU$250 in annual waste management charges. Alternative Waste Treatment is provided in 13% of control councils and 20% of treated councils, however, this difference is not statistically significant at any level. In terms of the provision of the red bin service, the difference in bin size between the two groups is not statistically significant but the

Table 1: Summary Statistics for Council Waste Characteristics in 2008

	(1) Control	(2) Treated	(3) Difference
Total Curbside Waste (kg/hh/wk)	19.701	21.129	1.427
	(5.852)	(8.133)	
Red Bin Landfill Waste (kg/hh/wk)	13.708	12.819	-0.889
	(5.688)	(6.647)	
Yellow Bin Dry Recycling (kg/hh/wk)	4.228	5.550	1.322**
	(2.618)	(2.352)	
Green Bin Garden Organic (kg/hh/wk)	1.765	2.760	0.995
	(2.950)	(3.222)	
Annual Waste Management Charges (AU$)	247.993	262.480	14.487
	(67.111)	(74.978)	
Alternative Waste Treatment (share)	0.130	0.200	0.070
	(0.337)	(0.407)	
Red Bin Size (L)	182.731	174.333	-8.398
	(61.143)	(55.066)	
Red Bin Frequency (collections per year)	51.278	48.067	-3.211**
	(4.293)	(10.445)	
Red Bin Spare Capacity (%/bin)	37.013	25.751	-11.262
	(25.388)	(58.809)	
Observations	108	30	138

Note: This table contains the mean values and standard deviations (in parenthesis) for the waste-related variables. Treated councils are those that adopt the FOGO program between 2010-2015 and control councils are those that that do not adopt. The two groups are compared on observations from 2008, a pre-policy period. Asterisks indicate the following: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

difference in frequency of pickup is statistically significant at the 5% level, with treated councils providing bin pickup 3 weeks less often per year on average.

Finally, we look at red bin spare capacity. If households are at their red bin limit prior to FOGO rollout, landfill waste may not decrease following policy adoption as these households may have pent-up demand for waste disposal services (i.e., they may previously have been stockpiling or dumping the waste that did not fit in their red bin). To calculate bin capacity, we first multiply bin size by bin frequency to get the total volume of waste households can dispose of in a given stream, measured in liters per year (we refer to this as bin capacity). For example, if a household has a 180L red bin that is collected weekly, the capacity of waste it can send to landfill each year is 9,360L. To convert liters into kilograms, we use the assumption that the density of municipal solid waste is 130 kg per cubic meter (NSW EPA, 2005). Finally, we divide the amount of red bin landfill waste collected by red bin capacity to calculate red bin space capacity. Table 2 suggests that both treated and control councils do in fact have extra capacity in their red bins prior to FOGO rollout, with the control councils having 37% spare capacity and the treated councils having 26% spare capacity.

Table 2: Summary Statistics for Council Demographic Characteristics in 2008

	(1) Control	(2) Treated	(3) Difference
Population (thousands)	50.727	37.695	-13.032
	(61.554)	(38.820)	
Area (km^2)	4,896.531	3,260.064	-1,636.468
	(8,718.704)	(4,264.546)	
Population Density (persons per km^2)	839.756	546.869	-292.887
	(1,610.178)	(1,331.308)	
Number of Households	19,245.584	15,084.467	-4,161.117
	(22,554.600)	(14,946.110)	
Ratio of Multi- to Single-Unit Dwellings	0.413	0.270	-0.143
	(1.777)	(0.518)	
Mean Income per Capita (AU$)	41,767.109	39,735.934	-2,031.178
	(16,193.251)	(16,051.741)	
Vote Share for Liberal/National Party (%)	68.418	70.015	1.597
	(13.013)	(11.931)	
Post-secondary Education (%)	53.375	54.523	1.148
	(8.952)	(7.608)	
Observations	108	30	138

Note: This table contains the mean values and standard deviations (in parenthesis) for the council demographic variables. Treated councils are those that adopt the FOGO program between 2010-2015 and control councils are those that that do not adopt. The two groups are compared on observations from 2008, a pre-policy period. Due to the lack of frequent data collection, the 'ratio of multi- to single-unit dwellings' and the 'post-secondary education' variables use 2011 data. Asterisks indicate the following: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In terms of council demographic variables, Table 2 shows no statistically significant differences between the treated and control councils. Nonetheless, population, land size, population density, number of households, and the ratio of multi- to single-unit dwellings are noticeably smaller for treated councils.[11] This is likely due to the fact that FOGO adoption occurs neither in councils that are rural and remote nor in councils in the Greater Sydney area which tend to be more more densely populated. Instead, FOGO adopting councils can best be characterized as suburban.

3 Empirical Design

3.1 Event Study Regressions

We estimate the causal effect of FOGO adoption on waste disposal behaviors using an event study design. The nature of the data, in that the councils are observed over multiple time periods, enables us to control for time-invariant council characteristics, as well as variation over time that effects all councils. Thus, to estimate the treatment effect, we employ the following two-way fixed-effect event study regression model:

$$W_{cy}^{B} = \sum_{\ell=-7}^{5} \beta_\ell FOGO_{\ell,cy} + \beta_2 GO_{cy} + \beta_3 R_{cy} + \beta_4 AWT_{cy} + \beta_5 X_{cy} + \alpha_c + \delta_y + \epsilon_{cy} \quad (1)$$

where W_{cy}^{B} is the outcome variable for council c in year y with respect to bin type B, α_c is a vector of council fixed effects, and δ_y is a vector of year fixed effects. $FOGO_{\ell,cy}$ is a dummy variable equaling one if council c in year y adopting FOGO ℓ years ago, with $\ell = 0$ denoting the year of adoption. GO_{cy}, R_{cy}, and AWT_{cy} are indicator variables equal to one if council c in year y have curbside dry recycling, curbside garden organic,

[11] Data on land size and the ratio of multi- to single-unit dwellings were collected from the Australian Bureau of Statistics' Census 2011.

and Alternative Waste Treatment, respectively. The primary outcome variables we use for W^B_{cy} are the average amount of waste collected per household-week in council c and year y for (a) red bin landfill waste, (b) yellow bin dry recycling, (c) green bin organic waste, and (d) total curbside waste. We will additionally look at the recovery rate, which is the yellow bin plus the green bin, divided by total curbside waste. The recovery rate is an important variable used by the NSW EPA to understand how much household waste is being recycled.

The β_ℓ vector is the parameter of interest, as it traces out the differences in outcomes between treated and control councils across event-time. Given FOGO adoption occurs throughout 2010-2015 and the data spans 2008-2015, ℓ ranges between -7 and 5. The year prior to FOGO adoption ($\ell = -1$) is the omitted category. The key identifying assumption is that, in the absence of the FOGO policy, waste disposal behavior in the treated and control councils trend in parallel. This means essentially that the control councils are a good counterfactual for the treated councils. We use the pre-policy portion of the β_ℓ vector to test this identifying assumption; there should be no trend in the β_ℓ vector prior to FOGO adoption (i.e., $\beta_{-7} = \beta_{-6} = ... = \beta_{-1}$). Related to the first assumption is the assumption that there are no contemporaneous shocks to the treatment group besides the treatment. Since this study uses multiple treatment periods, the shocks would need to vary in a similar patterns as FOGO adoption for this violation to occur. Finally, in addition to controlling for whether councils have curbside dry recycling, curbside garden organic, and Alternative Waste Treatment, we additionally include control variables (X_{cy}) that vary across council and years, namely median income and population, to make sure changing demographics are not driving the results.

4 Results

The figures in this section present the estimates from event study equation 1, where the $\hat{\beta}_\ell$ point estimates and 95% confidence intervals are displayed graphically. The standard errors are clustered by council and all regressions are reported with council and year fixed effects as well as control variables for dry recycling and garden organic curbside collection, Alternative Waste Treatment, mean income, and population.

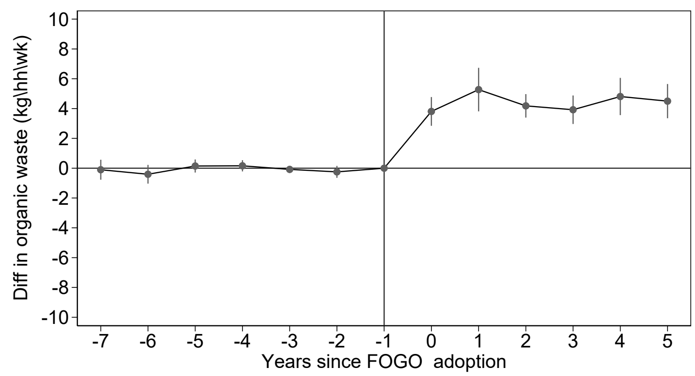
Figure 4 plots the results for (a) green bin organic waste, (b) red bin landfill waste, and (c) yellow bin dry recycling. With respect to the identifying assumption of parallel trends in the pre-policy period, in all three panels we find no evidence of diverging trends between treated and control councils in the 5 years prior to FOGO adoption (i.e., the pre-policy $\hat{\beta}_\ell$ are not statistically different from zero). In panel (b), for landfill waste, there is evidence of a differential trend 6-7 years before FOGO adoption, with landfill waste increasing in treated councils more than control councils. However, we are not overly concerned with these coefficients given the years closest to the adoption date show no pre-trend and, as the data spans 2008-2015 and FOGO adoption spans 2010-2015, there are fewer councils that have data 6-7 years prior to their FOGO adoption.

With respect to the post-policy $\hat{\beta}_\ell$, we find FOGO adoption had a large and persistent effect shifting waste from the landfill stream to the organic stream. Panels (a) and (b) show that in the first year of FOGO adoption, households increased the amount of waste in their green bins by 3.8 kg per week ($\hat{\beta}_0$=3.832), and decreased the amount of waste in their red bins by 4.1 kg per week ($\hat{\beta}_0$=-4.136). Both are statistically significant at the 1% level. This is consistent with our hypothesis that the FOGO bins make organic waste composting more convenient for households and encourages households to substitute food and garden waste from the red bin to the green bin.[12]

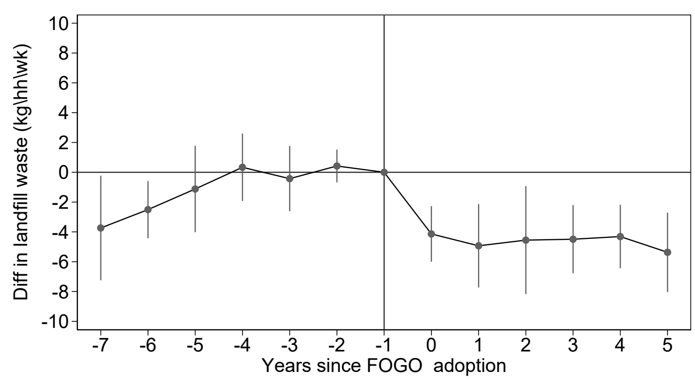
[12]These results are robust to using new event-study estimators developed to correct for potential

Figure 4: Effect of FOGO adoption on household curbside waste disposal, by bin type

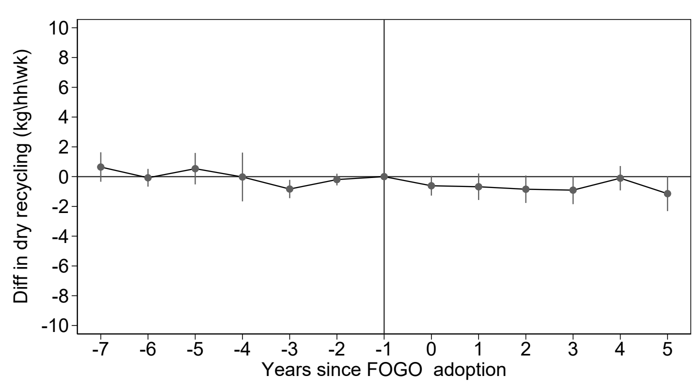
(a) Green Bin (Organic Waste)



(b) Red Bin (Landfill)



(c) Yellow Bin (Dry Recycling)



Note: The figure displays the $\hat{\beta}_\ell$ estimates from event study equation 1. The dependent variables are the average amount of waste (kg per household per week) disposed in a: (a) green bin, (b) red bin and (c) yellow bin. The 95% confidence interval are presented using standard errors clustered at the council-level.

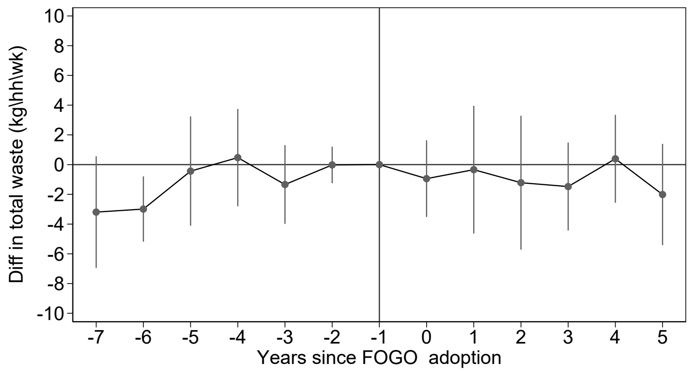
In terms of dry recycling, panel (c) suggests that dry recycling bins saw a small and marginally significant decrease after FOGO adoption. Specifically, in the first year of FOGO adoption, households decreased the amount of waste in their yellow bins by 0.6 kg per week ($\hat{\beta}_0$=-0.636, p-value = 0.060). This small crowding out effect could occur because of time constraints on waste sorting behaviors (i.e., the time taken to sort organic waste cannibalizes the time needed to sort dry recycling waste) or because of moral licensing, which is a psychological phenomenon where a past pro-environmental behavior produces a "license" to engage in less pro-environmental behavior (Gholamzadehmir et al., 2019). Alternatively, this small decrease in yellow bin waste could also occur if sorting FOGO waste causes households to do a better job sorting the organic matter out of their dry recyclables (i.e., less contamination in the yellow bin). However, given its marginal significance, we do not want to over-interpret this result.

In Figure 5, we additionally estimate event study equation 1 with outcome variables (a) total curbside waste, the sum of all three bins, and (b) the recovery rate, the share of total curbside waste going to either the green or yellow bins. With respect to total curbside waste, we find no statistically significant change due to FOGO adoption. This dispels concerns that households, upon having greater capacity to dispose of waste with the introduction of FOGO, consume more goods and consequently produce more waste. This is perhaps not surprising given households had spare capacity in their red bins prior to FOGO adoption, as shown in Table 1. Finally, in panel (b), the addition of the FOGO bin led to a 16.7 percentage point increase in the recovery rate. As there is little change in dry recycling and total waste, this is largely driven by the rise in

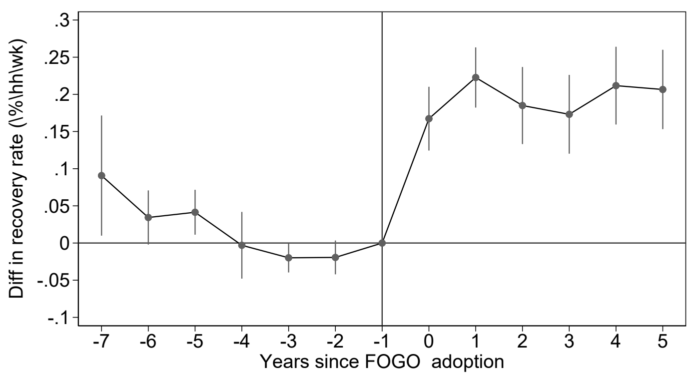
biases in OLS event-study regressions with two-way fixed effects (Goodman-Bacon, 2021; Callaway and Sant'Anna, 2020; de Chaisemartin and D'Haultfœuille, 2020; Baker et al., 2021; Borusyak et al., 2021; Sun and Abraham, 2021). As shown in Appendix Figure A1, we find little difference between OLS and the other estimators.

Figure 5: Effect of FOGO adoption on household curbside total waste and recovery rate

(a) Total Curbside Waste



(b) Recovery Rate



Note: The figure displays the $\hat{\beta}_\ell$ estimates from event study equation 1. The dependent variables are (a) the average amount of total waste (kg per household per week) disposed in curbside collection and (b) the rate of recovery, which is the share of total curbside waste going to either the green or yellow bins. The 95% confidence interval are presented using standard errors clustered at the council-level.

organic waste. Given the average recovery rate in 2008 was 31.4%, FOGO led to a 50% increase in the rate of waste that was either composted or recycled.

4.1 Persistency of the Treatment Effects

The event study plots are also useful for determining whether the impact of FOGO is one that persists over time. Figures 4 and 5 suggests that the effects of FOGO adoption are quite persistent, with the post-policy $\hat{\beta}_\ell$ coefficients in each panel fluctuating only slightly over the five years after FOGO adoption. From this it is clear that the policy has a continuing effect and that households do not revert to their pre-policy behavior. These lasting changes to household behavior as a result of changes to the curbside service are in line with the findings of Jenkins et al. (2003), who find households do not become less enthusiastic about participating in dry recycling programs over time.

Interestingly, this persistence also suggests that the substitution effect from the red to the green bin does not increase over time as individuals become more familiar with the new waste disposal system. Instead, individuals appear to be consistently engaging in the same degree of substitution. As shown by Figure 4(a), five years after FOGO adoption, treated household are still disposing 4.5 more kilograms of organic waste per week than control households ($\hat{\beta}_5$= 4.595). Given the average landfill waste per household per week for a treated council was 12.819 kg in 2008, this means roughly a third of what would have been landfill waste has now moved to the green bin under FOGO.

5 Effect of FOGO Adoption on Landfill Emissions

The previous section revealed that FOGO adoption reduced the amount of organic waste going to landfills by 4.5 kg per household per week. In this section, we use back-of-the-envelope calculations to translate this reduction in waste into an estimate for how much landfill emissions would be reduced if the entire state of NSW adopted FOGO.

First, we aggregate the household weekly landfill waste reduction to the state-year level using the number of households in NSW in 2015 (NSW EPA, 2021) and 52 weeks in a year. From this, we calculate a statewide FOGO program would reduce landfill waste by 718,936 tonnes per year. To convert tonnes of FOGO waste into tonnes of landfill emissions, we use estimates for the net impact on greenhouse gas emissions of composting FOGO waste instead of landfill. In Australia, these estimates range from -0.25 to -1.16 tonne carbon dioxide equivalent (CO_2e) per tonne of FOGO waste (Encycle Consulting, 2013; Biala, 2011).[13] In other words, the net impact of composting one tonne of FOGO waste instead of sending it to landfill is the avoidance of 0.25-1.16 tonnes of CO_2e. Thus extending our previous estimates, a statewide FOGO program would reduce greenhouse gas emissions from landfills by 179,734 to 833,966 tonnes CO_2e per year. Given landfills currently produce 3 million tonnes of CO_2e per year (NSW DPIE, 2021), this is a 6-28% reduction in greenhouse gas emissions from landfills.

While this range is large, even a 6% reduction in landfill emissions is economically significant as this reduction is almost entirely from methane emissions. Errickson et al. (2021) calculate the mean social cost of methane is US$933 per tonne. After translating tonnes of CO_2e into tonnes of methane using a conversion factor of 28 (Myhre et al., 2013), we calculate the value of a statewide FOGO program in terms of methane reductions would be US$6.0 to 27.7 million per year using the mean social cost of methane. If we take into consideration societal concerns about equity, these figures would be much higher. Extending their results to consider equity, Errickson et al. (2021) find the social cost of methane increases in high-income countries (up to US$8,290 per tonne in the US) and decreases in low-income countries (down to US$134 per tonne in sub-Saharan Africa). Given Australia is a high-income country, the equity-weighted value of methane reductions from FOGO adoption would be US$53.2–246.9 million per year.

[13] These estimates are country specific. For instance, the net impact on greenhouse gas emission of compost relative to landfill was -0.86 tonnes CO_2e per tonne organic waste in Italy (Blengini, 2008) and -2.3 tonnes CO_2e per tonne organic waste in Brazil (Markgraf and Kaza, 2016).

6 Conclusion

This paper utilized the large-scale, quasi-random adoption of Food Organics and Garden Organics (FOGO) by local governments in New South Wales (NSW) between 2010 and 2015 to measure the impact of this policy on the waste-disposal behavior of households. We find that FOGO adoption has a significant substitution effect on household waste. Specifically, households shifted approximately one third of their waste from the landfill stream to the FOGO stream.

Furthermore, the almost one-for-one substitution effect revealed other interesting elements of NSW household waste-disposal behavior. Prior to FOGO adoption, households were not facing a limitation on the amount they sent to landfill, with 25% spare capacity in their red landfill bins. Thus is it not surprising that FOGO adoption did not increase the total amount of waste being disposed. If households had been at full capacity before FOGO adoption, this may not have been the case.

With respect to dry recycling, the results show that FOGO has little net spillover effect on the amount of dry recycling. There is evidence of a small crowding out effect if anything. More importantly however, these results provide potential avenues for policymakers to address the problem of dry recycling management. Until recently, Australia exported a high proportion of its curbside recyclables to China. In 2017, however, China announced the National Sword Policy under which it severely limited plastic waste imports due to the high rate of contamination and the public health risk to workers.[14] As a result, some Australian sorting facilities have stopped accepting recyclable materials altogether (Downes, 2018) and councils have begun to stockpile dry recycling, which may pose a fire risk (Butler, 2019). Since food waste currently

[14] Since Australia's curbside recyclables have a contamination rate of 6-10% on average, they fall short of the rate acceptable under the policy- 0.5%.

takes up considerable space in landfills, it is worth considering how food waste management policies can have flow on effects for the temporary management of dry recycling until a longer-term solution is found. Our back-of-the-envelope calculations suggest that FOGO can clear up approximately 718,936 tonnes of space in NSW landfills per year. Currently, NSW households generate approximately 810,000 tonnes of dry recycling each year (NSW EPA, 2021), thus a large proportion of dry recycling could be temporarily redirected to landfills if necessary.

Back-of-the-envelope calculations also reveal how municipal composting services can be used to mitigate methane emissions from landfills—a key component of global efforts needed to limit temperature rise to 1.5°C this century (UNEP and CCAC, 2021). We calculate that statewide FOGO adoption would reduce landfill emissions by 6-28%. Since these reductions primarily come from reducing methane emissions, the value of these reductions could be as high as US$246.9 million per year (from just one state). Thus, municipal composting services are not only a cost-effective tool for handling organic waste (US EPA, 2021b), they also are an effective tool for governments to consider in the fight against climate change.

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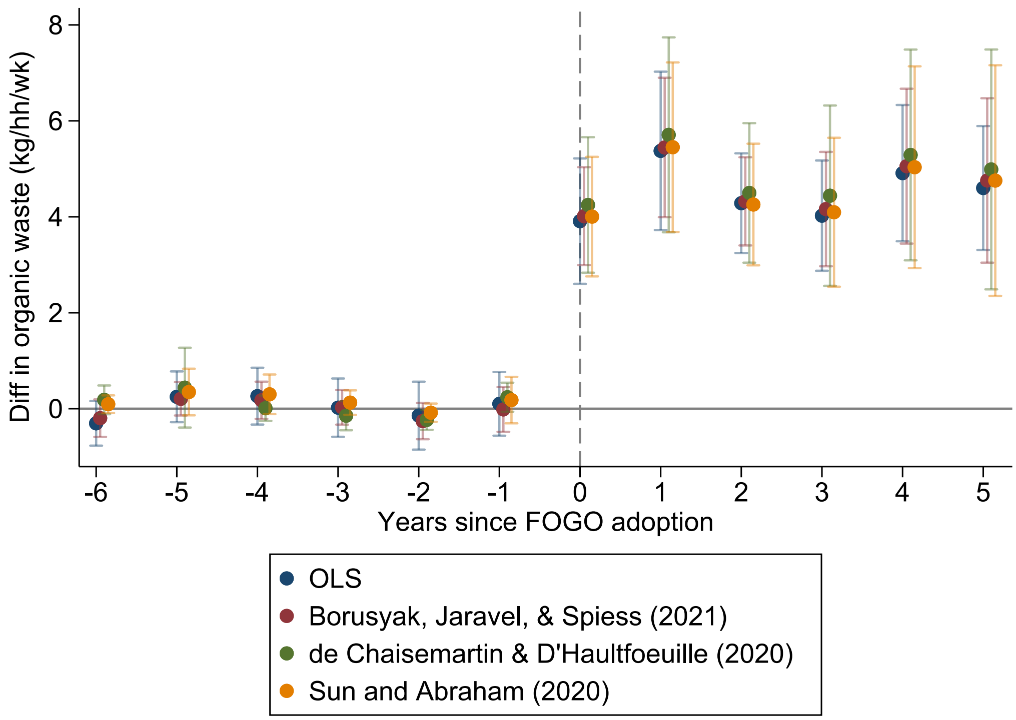
Appendix: Additional Tables and Figures

Figure A1: Robustness of OLS Event Study Specifications



Note: This figures compares the results from event study equation 1 estimated using Ordinary Least Squares (OLS) against the results using estimators developed by (a) Borusyak et al. (2021), (b) de Chaisemartin and D'Haultfœuille (2020), and (c) Sun and Abraham (2021). The 95% confidence interval are presented using standard errors clustered at the council-level.