The online retail of grocery is surging, analysts estimate that over 20% of groceries will be purchased online by 2025 [CNBC, 2017]. A number of well-funded firms are competing for this exciting opportunity. The world’s most successful online retailer, Amazon, with its $13.7 billion purchase of Whole Foods is expected to substantially expand its presence in this sector. Amazon Prime members can now get free two-hour delivery from Whole Foods. The grocery delivery startup, Instacart, has raised more than $400 million (US) and is now expanding its operations to more than 100 US cities. Peapod, the nearly 30-year-old online delivery company, plans to expand to new areas and is on its way to becoming a $1 billion business.

As an increasing number of households choose to shop online and enjoy the convenience of home delivery, it is important to ask whether online grocery retail is also good for the environment, or there is instead a hidden environmental price to this convenience. To understand the environmental impact of online grocery retailing, our study builds a stylized model of a fresh grocery supply chain with a twofold purpose: obtaining analytical insights on the drivers of emissions due to online presence, and using real data to calibrate the model in order to quantify the impact of online presence in practice. More specifically, we build a three-echelon perishable inventory model with an inventory-carrying supplier, and inventory-carrying retailers and households. Households and offline grocery stores are geographically distributed in the market. The supplier manages inventory in its warehouse so as to minimize its costs. Similarly, the offline retailers manage inventory at each store, while the online-grocer manages inventory at its hub and delivers groceries by optimally routing its fleet. Households choose between the offline and online retailers and buy and replenish groceries to meet their grocery needs.

Our model accounts for the two major sources of greenhouse gas emissions in fresh grocery retail: transportation and food waste [Cachon, 2014, Belavina, 2018]. Each tier generates travel emissions associated with transportation of groceries to replenish the grocery stock, and at each of the three tiers groceries that expire before being sold/consumed result in food waste, which also generates emissions.

We show that the impact of online grocery retailing on overall emissions depends on household shopping patterns captured by two metrics: online adoption (what percentage of households buy online) and online shopping frequency (how often online households buy grocery). The two metrics affect emissions at each tier in the supply chain differently. We find that, at the household level, online adoption has a non-monotone effect on emissions — they first decrease and then increase in
online adoption. This is due to a self-selection by the households — the ones who are located farther from stores, and, thus, travel and waste more, are also the ones who are most inclined to adopt as they gain the most from the convenience of online shopping. The pattern is reversed for the retail-tier emissions: they first increase and then decrease in online adoption. The decrease is surprising as, with the presence of the online-grocer, retail-tier inventory gets more decentralized (there is one additional location), and, thus, conventional wisdom would suggest that retail emissions should increase.

The departure happens because traditional models assume that demand gets split equally between all offline and online locations. However, our analysis shows that the online retailer collects some demand from all stores, which results in inventory decentralization with an unequal demand split.

When the online adoption level is low, indeed inventory decentralization is harmful. However, when it is high, the online-grocer has enough scale, and such decentralization is actually beneficial, and, in fact, can be thought of as centralization (enough inventory is flowing through one location, while other locations experience lower flow). We show that the equal demand split, in fact, has the worst outcome. That is, traditional models consider the worst kind of inventory decentralization.

As for the supplier emissions, we show they increase if and only if the combined consumer and retail food waste increases. Higher downstream food waste (unlike travel) drives higher emissions upstream by increasing the amount of grocery that needs to flow through the supply chain in order to meet demand. Waste further and further down the supply chain is more and more harmful: household waste is the worst as it rolls through the entire system.

By aggregating emissions at the three tiers of the supply chain, we establish that as online adoption increases, overall emissions first increase (retail emissions dominate), then decrease and increase (consumer emissions dominate) and then decrease (retail emissions dominate). The range for which online adoption increases emissions depends on how frequently online households shop. In particular, too low shopping frequency leads to excessive waste, and no adoption level can result in emissions improvement. Too high frequency has the same effect as it leads to excessive last-mile travel.

The online-grocer impacts household adoption and shopping frequency via its pricing policy: grocery price and per-delivery fee. Accounting for the effect of the pricing policy on households’ shopping pattern (adoption and frequency), we establish for each pricing policy if online-grocer with such policy is emission improving. The relationship is non-trivial, but can be roughly summarized as follows. The presence of the online grocer increases emissions when (1) too high prices cause very low adoption, triggering harmful effects of inventory decentralization, or (2) too low delivery fee leads to too frequent shopping by households, causing excessive last-mile travel, or (3)
too high delivery fee results in too infrequent household shopping, which leads to excessive food waste. In all other cases, the presence of online-grocer results in lower market emissions.

We calibrate our model with Census, licensing, and other grocery industry data for multiple cities. This analysis reveals that for all practical scenarios, an online presence is beneficial. Specifically, the three theoretical cases in which an online presence is harmful (described in the preceding paragraph) are not practically relevant. We observe with respect to case (1) that at online adoption levels above 2-4% (which is lower than current online adoption levels) decentralization is no longer a concern and is, in fact, beneficial. With respect to case (2), households would need to shop 4-5 times a day for last-mile travel to become a dominant factor. Inducing such shopping frequencies would require a negative delivery fee (to overcome existing frictional costs of online shopping); thus, practically, for all reasonable price-delivery fee combinations, the emission outcome is driven by the change in household waste, rather than by last-mile travel. With respect to case (3), a delivery fee above $12-13 would be required to induce too-infrequent shopping and thus lead to excessive food waste, while the optimal delivery fees computed for all cities considered are lower than $12, which is also in line with delivery fees set by the existing online-grocers.

In the final part of our study, we explore the emissions reduction potential of online retailing against another recently explored instrument: increasing the density of brick and mortar stores [Cachon, 2014, Belavina, 2018]. We show that when store density is very low, increasing density could be preferred over the development of an online outlet. However, for cities with sufficiently high store density (all cities for which we calibrated our model meet this requirement) online presence is substantially more efficient as far as environmental impact is concerned. Online presence is more efficient as it attracts households for whom offline shopping is least convenient, which, as a result, also tend to be the households with worst environmental impact, while higher store density impacts households in a less targeted fashion and, thus, is more efficient only in very low store density scenarios. Finally, we show that, compared to delivery from a separate online hub, making online deliveries from existing offline stores is more environmentally friendly. This suggests that a hybrid online-offline structure, alike to one that could be created by Amazon’s acquisition of Whole Foods, may, in fact, lead to the most environmentally-efficient fresh grocery supply chain.

References


CNBC. Online grocery sales set to surge, grabbing 20 percent of market by 2025. cnbc.com, 2017.