Customer-Employee Substitution: Evidence from Gasoline Stations*

Emek Basker† Lucia Foster‡ Shawn Klimek§

May 2017

Abstract

We document the adoption of self-service pumps in U.S. gasoline stations from 1977 to 1992. Using establishment-level data from the Census of Retail Trade over this period, we show that self-service stations employ approximately one quarter fewer attendants per pump, all else equal. The work done by these attendants has shifted to customers, biasing upwards conventional measures of productivity growth.

JEL Codes: D22, D24, J23, L81

Keywords: Customer-employee substitution, retail, gasoline station, self service, full service, outsourcing

*Comments welcome. Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the U.S. Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed. A previous version of this paper circulated with the title "Customer-Labor Substition." We thank Andrea Shepard, Ivan Png, and David Reitman for the Lundberg data; John Nogle for help with historic Census of Retail Trade data; CY Choi for help with the ACCRA data; and Chris Adams, Phillip Antopitov, Saku Aura, David Autor, Randy Becker, Jim Bessen, Roger Betancourt, Andrew Foote, Anne Hall, John Haltiwanger, Russell Hillberry, Henry Hyatt, Ron Jarmin, Richard Kneller, Mark Lewis, Florin Maican, Kristin McCue, Peter Mueser, Matilda Orth, Ivan Png, Henry Schneider, Jim Spletzer, Patrick Warren, seminar participants at IFN–Stockholm, Bureau of Economic Analysis, George Washington University, University of Michigan, George Mason University, Federal Trade Commission, the 2015 IIOC (Boston), the 2015 BLS-Census Workshop, and the 2015 Comparative Analysis of Enterprise Data (Istanbul) for helpful comments and conversations.

†U.S. Census Bureau; contact: `emek.m.basker@census.gov`

‡U.S. Census Bureau; contact: `lucia.s.foster@census.gov`

§U.S. Census Bureau; contact: `shawn.d.klimek@census.gov`

1 Introduction

Increasingly in the service sectors, customers are performing tasks previously done by paid employees: they withdraw, deposit, and transfer funds using Automated Teller Machines (ATMs); book travel online without the aid of a travel agent and check in using automated kiosks at airports; check out at supermarket "self-checkout" lines; use tablets to order and pay at restaurants; and access customer-service functions online or through an interactive voice response telephone call.[1] In these and other settings, customer-employee substitution is a solution to the problem of automating tasks that are resistant to computerization. These manual tasks have proven challenging to automate and computerize because they require "situational adaptability, visual and language recognition, and in-person interactions" and "must be produced and performed largely on-site or in person" (**?**, p. 12).[2] Although a *person* is needed to perform the task, that person need not be an employee. Indeed, the one person who is guaranteed to be on site at the time of the transaction and to understand the customer's wishes and needs is the customer herself.

From a perspective of productivity measurement, customer-employee substitution poses a unique quandary. Whereas true automation reduces labor input, customer-employee substitution merely substitutes one type of labor, which is observed, with another type of labor, which is unobserved.

In this paper, we use a case-study approach to study the transformation of gasoline stations and the effects of integrating customers into the production function. To this end, using station-level data from the Census of Retail Trade (CRT) over the period from 1977 to 1992, we estimate a production function taking into account the specific features of that production: namely, that a car, a gasoline pump, and a worker (who may be a paid employee or the unpaid driver of the car) must all be present at the same place for a fixed number of

[1]In the terminology of **?**, customer-employee substitution may also be associated with a reduction in the distribution service *ambiance*. It is also called "co-production" (**?**) or "cost shifting" (**?**).

[2]For a further discussion on the ability of computers to automate mechanical work, see **????**.

minutes. We estimate two key parameters of this production function: the productivity of attendants at full-service pumps and the productivity of attendants at self-service pumps. The ratio of these two allows us to infer the labor input due to customers, which we put at approximately one quarter of the labor input in self-service stations. We then estimate both physical and revenue measures of gas-station labor productivity, and demonstrate that ignoring the role that customers play in the production function leads to upward bias in measured productivity.

The self-service format in gasoline stations has been traced to a Urich Oil station in Los Angeles in 1947 (**?**). The same source estimates that only one percent of gas stations offered self-service pumps in 1969. The Census Bureau started collecting information on self-service options at gas stations in 1972. (Establishment-level data are available starting in 1977.) Table 1 provides summary statistics from published Census of Retail Trade (CRT) tables for 1972, 1977, 1982, 1987, 1992, and 1997. Over this period, the total number of US gasoline station declined, and the share of gas stations providing some self-service sales of gasoline increased from 8% to 80%.[3]

The paper contributes to a broader discussion on productivity measurement, particularly in retail and services. Retail productivity is hard to measure because output is multi-dimensional (see **?**, for a general discussion); in the language of **?**, retailers offer not only explicit goods for sale but also "implicit distribution services," which are fundamentally unmeasurable (p. 6). In addition, unlike in the manufacturing sector, capital is typically measured as square footage, or not at all; infrastructure and other capital investments are

[3]Under the Standard Industrial Classification (SIC) system, which was used until 1997, most gasoline stations were included in SIC 554, for which published statistics exist. However, convenience stores with gasoline stations — in other words, establishments whose primary business was operating a convenience store — were classified under SIC 541130 and rarely tabulated separately from other convenience stores. As the business model shifted from gasoline stations without convenience stores to combination gas station/convenience stores, this group of stations became relatively more important. We have tabulated these in Table 1 from the micro data. Over time, these stations increased from a negligible 3% of all stations to 18%, so that excluding them dramatically exaggerates the decline in the number of gas stations over this period.

rarely, if ever, included in retail-productivity calculations. Customer-employee substitution adds another dimension to the measurement problem by introducing a non-measured component. The difficulty is not simply that customers participate in the production of final goods but that the nature of their participation has changed over time. If we think of the customer's work as another input into the production function, customer-employee substitution means that we are completely missing information on one input. If we think of the customer's work as a component in total labor, then customer-employee substitution means that we are mismeasuring the labor input. In either case, the aggregate input measure is biased downwards and this bias increases as more stations adopt self-service technologies. Thus, true productivity may increase, particularly due to a reduction in idle time, but measured productivity increases disproportionately more. Moreover, the (multi-dimensional) output itself has changed as one of the bundled services (an attendant delivering gasoline into the customer's car) has disappeared.

We describe the datasets used in the analysis in Section 2. Section 3 provides background on the adoption of self service and describes reduced-form regression results correlating adoption with observed factors. Section 4 presents a theoretical framework and estimates of the labor-saving impact of self-service stations. Section 5 demonstrates the bias in conventional productivity measures that do not account for customer-employee substitution and for the other major trend in gas stations over this time period, which is the bundling of convenience stores into gas stations. Section 6 concludes.

2 Data

Our primary data set is constructed from establishment-level responses to the 1977, 1982, 1987, and 1992 Census of Retail Trade. The CRT is a quinquennial (five-year) census of all retail establishments conducted as part of the Economic Census. We focus on gasoline stations (SIC 554110) and gasoline stations with convenience stores (SIC 554130, introduced in 1987). We refer to these, collectively, as gas stations. Longitudinal links and establishment age are provided by the Longitudinal Business Database (LBD).[4] This section describes the CRT sample construction in some detail. Additional data sources are described in Appendix A.1.

For each station that completed CRT form 55D (in 1977) or 5504 (in subsequent years), we have detailed data on inputs and outputs. On the input side we have information about both labor (employment the week of March 12) and capital (the number of gasoline pumps the station operates as of December 31 and, if it offers self-service, the number of those pumps that were designated for self service on December 31).[5] On the output side we have gallons sold, by service level, over the calendar year, as well as total revenue for the calendar year broken down by product lines — such as revenue from sale of gasoline, groceries, tobacco products, auto parts, and repair services.[6]

We infer whether a station has a convenience store or offers repair services from revenue reports. To be conservative, we identify a station as having a convenience store if it reports any revenue from the sale of food, alcohol, or tobacco products. Similarly, we identify a station as having a repair shop by the station's reporting receipts from repair services.

We restrict the CRT sample by removing approximately 20,000 stations that do not report a revenue breakdown. We also drop a small number of stations that provide internally inconsistent answers on the forms, for example stations that report more than 100% of their

[4]For background on the LBD, see **?**. The LBD starts in 1975, so station age is censored at two in 1977, seven in 1982, 12 in 1987, and 17 in 1992; for this reason our age variable in all regressions is an indicator for the station being at least two years old.

[5]Pump configuration was generally fixed for long periods of time; stations did not change pumps from self service to full service or *vice versa* for weekends, holidays, or other special occasions. Regular customers knew which pumps were designated as self service and which as full service and would pull into the appropriate lane. Typically, pumps closer to the booth or convenience store were designated full service, as they were more easily accessible by the attendant.

[6]Economic Census data are the only source for many of the variables we use. Some variables, including employment, come from administrative sources and are extremely reliable. Other variables, including number of pumps and availability of self-service pumps, are self reported on CRT forms and may be subject to reporting and measurement error. We have a unique opportunity in this case to check a subset of the data by cross-tabulating it with another source, as detailed in Appendix A.2.

gasoline pumps are self-service, and a few stations that report being active zero months of the year, report operating 75 or more gasoline pumps, or report selling fewer than 5,000 gallons per gasoline pump.

The CRT generally does not include information on the brand name associated with each station but it does include an identifier for the owning firm, allowing us to link stations owned by the same firm. If the firm also owns a refinery (SIC 2911), the same firm identifier is also included in Census of Manufacturing. Stations that belong to multi-unit firms may be part of horizontal chains or be vertically integrated. We tag stations as vertically integrated if they belong to a firm that also operated at least one refinery in the same year. Multi-unit and vertically integrated stations may have different labor practices and different propensities to adopt the self-service model (**??**).

Table 2 shows summary statistics. We round observation counts to the nearest hundred to comply with Census rules on disclosure avoidance. Our sample of stations with complete valid data on the variables we use in our analysis includes approximately one third of all gas stations in the U.S. each year (from Table 1).[7]

3 Adoption

Before we turn to estimating the gas-station production function in the next section, we present some descriptive evidence on the adoption margin. We focus on three types of variables: station characteristics (station age and size, ownership by a multi-unit or vertically integrated firm, and the presence and size of a convenience store and/or repair shop); local competition (modeled as the log of the number of gasoline stations in the county, from published County Business Patterns tables); and local regulation in the form of the state minimum wage and self-service bans.

[7]Compared to the full set of stations, the stations in our sample have, on average, approximately 20% higher employment and revenues; they are also 50% more than likely to belong to multi-unit firms and twice as likely to belong to vertically integrated firms.

Bans on self service explain a very large share of variation in adoption rates. New Jersey and Oregon have banned self-service pumps since 1949 and 1951, respectively, and several local bans have also been in place for all or part of our sample period.[8] Figure 1 shows self-service adoption over time in the U.S. The top, solid, line shows the fraction of pumps used for self service $\left(\frac{K_s}{K_f+K_s}\right)$, which we refer to as self-service intensity, averaged each year across all stations not subject to a self-service ban. The bottom, dashed, line shows the same for stations subject to a self-service ban. Some stations in locations with self-service bans do report having self-service pumps, but this fraction is under 5%, as compared with 70% over the full sample period in locations without a ban. This could reflect either measurement error or stations that are exempt from the regulation, for example, stations that serve private vehicles fleets.

We use a regression framework to study other correlates of adoption. In our regressions, we omit stations subject to bans. The LHS variable is the ratio of self-service pumps to all pumps. We include year fixed effects in all specifications, since aggregate trends are clearly central to adoption.[9]

[8]Local bans are in place in four Massachusetts cities (Arlington, Holbrook, Weymouth, and Upton) and in Huntington, NY. Two other New York towns, East Hampton and the Village of Patchogue, repealed their bans in the late 1980s. Justifications for the bans, both at the state and local levels, generally relate to public safety and protecting jobs.

[9]Two oil shocks, one in 1974 and one in 1979, likely played a role in the acceptance of self service. At its peak in 1981, the real price of crude oil was more than four times the level from 1972. The income effect of higher gasoline prices appears to have increased demand for options that lowered the price, however marginally. (Perhaps relatedly, **?**, documents that the adoption of self-service in South Korea also spiked following oil shocks, in this case in the late 2000s.) In addition, improvements in cars lengthened the time intervals between required oil changes and reduced the need to check belts, hoses, and fluids at every fill-up; moreover, newer models, starting in the 1980s, included malfunction indicator lights to let drivers know their oil needed to be checked. Describing the 1970s, a gas-station owner recalls: "We would always ask the customer if they wanted us to check their oil and water [. . . .] It was easy to bring in extra income just by opening the hood of a car" (**?**, p. 12). Two-sided network effects associated with customer learning are also likely to be important: once a customer learns to refuel his car, he may be more amenable to doing so again, either at the same station or at a different station.

We estimate

$$\frac{\mathrm{K}_{s,it}}{\mathrm{K}_{f,it}+\mathrm{K}_{s,it}} = \delta_t + \phi_1 \ln(\mathrm{K}_{it}) + \phi_2 \mathrm{age2}_{it} + \phi_3 \mathrm{multiunit}_{it} + \phi_4 \mathrm{vertical}_{it} + \phi_5 \mathrm{convenience}_{it} + \phi_6 \mathrm{repair}_{it} + \phi_7 \ln(\mathrm{stations}_{it}) + \phi_8 \ln(\mathrm{minwage}_{it}) + X_i\beta + \nu_{it} \quad (1)$$

where i indexes a station and t the year; δ_t are year fixed effects; K_{it} is the total number of pumps the station operates; $\mathrm{age2}_{it}$ is an indicator for a station being at least two years old; $\mathrm{multiunit}_{it}$ is an indicator for the station being part of a multi-unit firm, and $\mathrm{vertical}_{it}$ is an indicator for the firm being vertically integrated; $\mathrm{convenience}_{it}$ and repair_{it} are indicators which equal one if the station operates a convenience store or a repair shop, respectively; $\mathrm{stations}_{it}$ is the number of gas stations in the county of station i in year t, from County Business Patterns; and $\mathrm{minwage}_{it}$ is the state minimum wage (see Appendix A for sources). The vector X_{it} may include state, county, or station fixed effects. In some specifications we replace the convenience and repair indicators by dollar revenues from different sources; these are not logged because many observations have no revenue from one or more sources. The error term ν_{it} is clustered by state.

The results are shown in Table 3. Several interesting patterns emerge. First, across all specifications, larger stations (as measured by total pumps) are more intensive adopters, and older stations are less intensive adopters (in specifications with station fixed effects, this variable is not statistically significant).[10]

Second, self-service intensity is positively correlated with the presence and size of a convenience store, but negatively correlated with the presence and size of a repair shop. These results are consistent with findings reported elsewhere: **?** use published state-level data from the CRT and find a positive association between the percentage of stations offering self-

[10]The total number of pumps appears in the denominator of the LHS variable and, logged, as an independent variable on the RHS. All results are qualitatively and quantitatively stable if we omit it from the regressions.

service and both total gasoline sales and the percentage of stations selling food, and a negative correlation between the percentage of stations offering self-service and the percentage of stations with service bays. **?**, using cross-sectional station-level data from a February 2000 survey of stations in New Jersey and Pennsylvania, find that stations offering self-service (in Pennsylvania only) have more pumps and are more likely to have convenience stores than full-service stations, but are less likely to offer repair services.

Third, multi-unit status is positively correlated with self service. Vertical integration is also positively correlated with self service, unless station fixed effects are included, in which case the variable is no longer significant. The absence of statistical significance (and the change in sign, although the magnitude is very small) is likely due to the fact that there is very little variation in the vertical structure of stations over the sample period. This result is also consistent with prior research: **?** uses firm-level data from published sources for 24 Canadian oil companies in 1973 and 1974, and finds that larger firms were more likely to adopt self service, as were firms with more lessee-dealer-operated stations.[11,12]

Fourth, competition is correlated with higher self-service rates, but again this masks unobserved county and station characteristics; controlling for either county or station fixed effects, competition is negatively correlated with self service.

Finally, a higher minimum wage is positively correlated with adoption. To our knowledge, this relationship has not been documented elsewhere. This result, which is robust across all specifications, suggests that labor costs are an important determinant in the adoption decision. The positive relationship between minimum wage and self-service adoption complements findings by **?** that increases in the minimum wage reduce employment in cognitively routine occupations but not in manually routine or non-routine low-wage occupations.

[11] **?**'s finding that firm size is correlated with adoption may be spurious because the LHS variable in his regressions is an indicator that turns on if *any* station operated by the firm has adopted self service. Larger firms have more stations, and so are mechanically more likely to have the indicator on even if each station is equally likely to adopt the new model.

[12] We have also estimated these regressions with firm fixed effects; the coefficient on vertical integration cannot be separately identified in this specification, but other results are robust.

Gas-station attendants' jobs are manually routine and are therefore not easily automated (**?**). In our setting, however, automation is supplemented by the ability of the customer to assume any cognitively non-routine tasks.[13]

We have also estimated this regression with a sample limited to observations from 1982–1992, using initial (1977) conditions as the explanatory variables. Not surprisingly, a station's 1977 self-service adoption intensity is strongly positively correlated with future adoption intensity. The other variables have the same signs as above: initial station size, multi-unit, and vertically integrated status positively predict future self-service adoption; initial station age (weakly) negatively predicts future self-service adoption; convenience and repair indicators have positive and negative signs, respectively. (The full table is omitted to comply with Census rules on disclosure avoidance.)

4 Labor Saving

Specifying production functions in the retail context is a difficult task, as noted by **?** and **?**, among others. Among the difficulties is the fact that retail is a service, and output is therefore tricky to measure; data on inputs, in particular capital and customer labor, are also often lacking. In our context we are lucky on a number of dimensions: first, the service level is explicitly measured, and the CRT collects information on gallons sold. The difficulty estimating the degree of substitution of employee labor by customer labor, instead, is due to the fact that we do not observe the number of attendants at each station. Instead, we observe the number of *employees*, only some of whom are attendants. Other employees may be working at the convenience store (selling or stocking), the back office (payroll, pricing,

[13]Attendants in full-service stations did much besides pumping gasoline and collecting payment; they also checked oil and belts, repaired flat tires, and more. In a children's book from 1972, an attendant named Jim describes his job: "Sometimes I prepare a charge slip for a credit-card customer. I set up displays of oil and tires, and keep a count of those items. I provide highway maps and keep candy bars for hungry travelers" (**?**, p. 23). A workbook for aspiring gas-station attendants from the same era includes instruction on these tasks as well as on checking gasoline inventory (**?**).

advertising, accounting, legal departments), repairing cars, or doing general station maintenance. We observe some information that is correlated with the extent to which these tasks require employees — for example, we infer the presence of a convenience store from the station's reports of revenue lines, and the need for independent accounting and payroll functions from the fact that a station is not part of a large chain — but we do not know the extent of these requirements. We rely on a simple model of retail-gasoline production to address this problem.

4.1 Theoretical Framework

4.1.1 Full Service

Retail gasoline production is well described by a Leontief production function: each pump requires both a car and an attendant to produce output, and likewise an attendant requires both a car and a pump. There is no way to substitute one input for another.

We assume that refueling a car takes a fixed number of minutes μ, and therefore measure production in μ-minute intervals indexed by m. For a full-service station, output during interval m is

$$\mathrm{G}_{fm} = \gamma \min \left\{ \frac{\mathrm{L}_{fm}}{\alpha_f}, \mathrm{K}_f, \mathrm{C}_{fm} \right\}$$

where G_{fm} is the total output, measured in gallons; γ is the number of gallons purchased per customer; L_{fm} is the number of pump attendants; α_f is a technology parameter; K_f is the (time-invariant) number of pumps; and C_{fm} is the number of customers (equivalently, cars) seeking fueling during interval m. The Leontief nature of the production function forces a $1:1$ ratio of cars to fuel pumps in use, but allows for the possibility that a single attendant can refuel multiple cars (if $\alpha < 1$) or that more than one attendant is needed per car (if $\alpha > 1$).

Our data are annualized, so we need to aggregate the μ-minute intervals to a full year. There are $\frac{60}{\mu}$ such periods per hour, or $\frac{10{,}080}{\mu}$ periods per week. Summing L_{fm} over all intervals m in a given week gives

$$\sum_{m=1}^{\frac{10080}{\mu}} \mathrm{L}_{fm} = \eta \mathrm{L}_f$$

where L_f is the total number of attendants employed at the station and η is the number of hours worked by each of them. This accounting identity holds as long as η is constant, even if the station is closed (i.e., $\mathrm{L}_{fm} = 0$) during some periods.

The number of cars is not under the direct control of the station, but is indirectly affected by the price charged per gallon and by other factors outside the station's control, such as the day of week, time of the day, season, weather, and competitive environment; we assume that C_{fm} can be accurately anticipated by the station for each interval m. Then, as long as $\mathrm{C}_{fm} \leq \mathrm{K}_f$, optimization requires that the station chooses the number of attendants so that $\frac{\mathrm{L}_{fm}}{\alpha_f} = \mathrm{C}_{fm}$.[14,15] In an hour with L_{fm} attendants, the total number of customers served is $\frac{60}{\mu}\frac{\mathrm{L}_{fm}}{\alpha_f}$. Therefore, over the course of a year, the total number of customers served is

$$\mathrm{C}_f = 52 \cdot \sum_{m=1}^{\frac{10,080}{\mu}} \frac{60}{\mu}\frac{\mathrm{L}_{fm}}{\alpha_f} = \frac{3120}{\mu\alpha_f} \cdot \eta \mathrm{L}_f$$

From the production function, the number of customers per year is also $\frac{\mathrm{G}_f}{\gamma}$. Equating the two expressions and solving for L_f, we get

$$\mathrm{L}_f = \frac{\mu\alpha_f}{3120\eta}\frac{\mathrm{G}_f}{\gamma}.$$

[14] If $\mathrm{C}_{fm} > \mathrm{K}_f$, the station cannot accommodate all its customers, and should raise its price.
[15] We ignore integer problems with respect to all inputs.

4.1.2 Self Service

For a self-service station, we postulate a production function that differs in only one parameter – employee productivity:

$$\mathrm{G}_{sm} = \gamma \min \left\{ \frac{\mathrm{L}_{sm}}{\alpha_s}, \mathrm{K}_s, \mathrm{C}_{sm} \right\}$$

where the subscript s now denotes self service. Implicit in this function is the added effort required of the customer, C_s; the customer effort partially replaces the attendant's labor input. Like full-service customers, self-service customers are an input not under the direct control of the station, but indirectly controlled through pricing. If no attendants are needed at a self-service station then $\alpha_s = 0$. At the other extreme, if equal attendant effort is required in full-service and self-service stations, $\alpha_s = \alpha_f$.[16]

The same optimization issues apply here. If the number of attendants is just sufficient to meet demand, then the number of attendants employed by the station in any given week is

$$\mathrm{L}_s = \frac{\mu \alpha_s}{3120\eta} \frac{\mathrm{G}_s}{\gamma}.$$

4.1.3 Total Employment

Although gas stations are generally considered single-product retailers, the reality is more complex, since many stations have repair shops (particularly in the early part of our sample) or convenience stores (particularly in the latter part); employees are also required for other tasks, such as management, purchasing, accounting, and pricing. We therefore assume that

[16] In some jurisdictions, there may be legal as well as technological requirements for a minimum level of employee labor. For example, current law in Michigan states: "At least one attendant must be on duty while the station is open for business. The attendant's primary function shall be to supervise, observe, and control the dispensing of the liquids" (http://www.michigan.gov/lara/0,4601,7-154-42271_4115_4238-9319--,00.html, accessed June 22, 2016).

each station requires some fixed labor input, L_0. Total employment in a full-service station is $L^{fs} = L_0 + L_f$ and at a self-service station it is $L^{ss} = L_0 + L_s$.

Approximately 30% of the stations in our sample offer both full-service and self-service pumps. For these, we assume that production is

$$\mathbf{G}_m = \begin{bmatrix} G_{fm} \\ G_{sm} \end{bmatrix} = \gamma \cdot \begin{pmatrix} \min\left\{\frac{L_{fm}}{\alpha_f}, K_f, C_{fm}\right\} \\ \min\left\{\frac{L_{sm}}{\alpha_s}, K_s, C_{sm}\right\} \end{pmatrix},$$

total employment is $L = L_0 + L_f + L_s$, total pumps are $K = K_f + K_s$, and the total number of customers is $C = C_f + C_s$. Aggregation to annual levels follows the same logic as above.

Our model abstracts from idle time by assuming a constant arrival rate of customers. If arrival is random, for example following a Poisson arrival rate, then the switch from full-service to self-service has an additional effect, because pump idle time and labor idle time no longer coincide. If there is no attendant waiting for a customer, the pump can be idle without imposing that there also be idle labor. The worker — in this case embodied in the customer — arrives, and leaves again, at the same time as the customer. This suggests that the price discount offered to customers may exceed the cost of the worker serving the customer, because it also includes the cost of the worker waiting for the customer. Once pay-at-the-pump technology is introduced, the pumps can be used even at times when there are no attendants present. Consistent with this intuition, the average of gallons per pump is higher in self-service stations than in full-service stations, and for self-service pumps relative to full-service pumps in mixed stations (see Table 2).

4.2 Estimation

Guided by the production function above, we estimate OLS regressions to recover two labor-productivity parameters, α_f and α_s. We are less interested in their levels and more in their relative magnitudes, which tell us about the relative contribution of customer labor in the production function.

Total employment at station i in year t is

$$\mathrm{L}_{it} = \mathrm{L}_{0,it} + \alpha_f \left(\frac{\mu \mathrm{G}_{f,it}}{3120\eta\gamma} \right) + \alpha_s \left(\frac{\mu \mathrm{G}_{s,it}}{3120\eta\gamma} \right) + \varepsilon_{it}$$

The parameters η, γ, and μ are assumed to be constants:

1. Hours worked per week (η): In the CPS-MORG file for 1979–1992, the average reported hours worked last week, at all jobs, for respondents whose industry is given as a gas station, whose occupation is given as a cashier or attendant, and who reported working at least one hour was about 34.5; the average "usual hours" at the main job was 33.5. We use $\eta = 34$ hours.

2. Refueling gallons (γ): **?**, using survey data from over 500,000 fill-ups by 5,000 families in 1980 and 1984, finds that the average number of gallons purchased per refueling for a range of options (leaded vs. unleaded, full serve vs. self serve, regular vs. premium) is about 10.5. There is no statistically significant difference between full-service and self-service gallonage and no statistically significant difference between 1980 and 1984. **?**, using data from a survey of 170 cars in 1980, also found an average of 10.5 gallons per fill-up. We use $\gamma = 10.5$ gallons.

3. Refueling time (μ): **?** estimate a refueling-time regression using an unspecified number of observations from two stations in Massachusetts over the course of two days in 1974; using their coefficient estimates, the predicted service time for a 10.5-gallon purchase is 2:35 minutes. **?**, in a study about health effects of self-service fueling, report the median refueling time in their sample of 130 observations of 39 individuals in 1998 and 1999 was three minutes, and the range was 1–10 minutes. Finally, **?**, using data from 399 fill-ups in both full- and self-service stations in New Jersey and Pennsylvania over the spring and summer of 2006, finds that the average car takes under four minutes to refuel. To allow time for payment (most of our sample predates pay-at-the-pump

technology) and additional maintenance that was required for older car models, such as checking tires, oil, and belts, we use $\mu = 4$ minutes.[17,18]

Given these parameters, we define

$$\begin{aligned}\widetilde{\mathrm{G}}^f &= \frac{\mu}{3120\eta\gamma}\mathrm{G}_f = \frac{\mathrm{G}_f}{278460} \\ \widetilde{\mathrm{G}}^s &= \frac{\mu}{3120\eta\gamma}\mathrm{G}_s = \frac{\mathrm{G}_s}{278460}\end{aligned}$$

to estimate regressions of the general form:

$$\mathrm{emp}_{it} = \alpha_0 + \alpha_f \cdot \widetilde{G}^f_{it} + \alpha_s \widetilde{G}^s_{it} + X_{it}\theta_x + \varepsilon_{it} \tag{2}$$

where **emp** is station employment (a positive integer). Importantly, the same parameters modify both full- and self-service gallons. Our main interest is in the ratio of the coefficients $\frac{\alpha_f}{\alpha_s}$, which is unaffected by the precise value of the parameters.[19]

We estimate the model both with and without control variables X_{it}. Control variables may include year fixed effects; state fixed effects; state-year fixed effects; an indicator for a station being at least two years old; indicators for the station being owned by a multi-unit and/or vertically integrated firm; indicators for the presence of a convenience store and/or a

[17] The earliest reference we have found to the payment technology is from 1983, halfway through our sample. In 1983, Conna Corp. of Kentucky reported planning "a computerized system that will be among the first in the nation to allow customers to use a credit card or bank card to pay at the pump without an attendant handling the transaction" (?). Other companies conducted early tests in California in 1983 and in Oklahoma in 1985 (??). But the technology did not catch on immediately; as of 1993, after the end of our sample, the leading installer of card readers, Mobil Corp., had readers installed in fewer than 25% of its stations (?). Our data do not include information on whether the station has card readers available at the pump.

[18] A Ford Owner's Manual for 1980s models advised drivers, "Check the engine oil level every time you fill the gas tank" (?, p. 1–31).

[19] We do not use the third input in the production function — the number of pumps — in our estimation. From Table 2, note that the number of gallons sold per pump ranges from approximately 100,000 (in full-service stations) to 150,000 (in self-service stations). Assuming each fill-up takes four minutes and accounts for 10.5 gallons, the average pump is in use between 670 and 960 hours per year. For a station open 365 days per year, this is equivalent to between 1.83 and 2.63 hours per day. This low capacity utilization is consistent with the evidence in ? that stations can charge a premium if they have no wait time.

repair shop, or real revenues from these operations; and establishment fixed effects. Standard errors are clustered by station, allowing for arbitrary autocorrelation.

The multi-unit and vertical-integration indicators capture the fact that large firms may have different employment practices; in particular, they may employ fewer people at the station and more people at headquarters in administrative jobs. Even among vertically integrated firms, different organizational forms may have different employment practices; for example, company-operated stations, which are managed by company employees, may have more or fewer employees than lesee-dealer stations, owned by the refiner but operated by a residual claimant.[20] These firms may also have different rates of adoption of self service (**?**), leading to biased estimation of the α coefficients if this control is omitted. Similarly, a station with a convenience store or a repair shop has different fixed-labor requirements, and at the same time may have different rates of adoption to the extent that service level and other station amenities are complementary. Controlling for station age is important because older surviving stations tend to be larger, and they are also less likely to have self service. Most of the variation in station employment that is correlated with station age is soaked up by this indicator.

Year fixed effects capture average differences in self-service adoption over time, which may also be correlated with other trends in labor demand or labor supply, such as changes in station hours. Station fixed effects allow us to control with greater precision for both observed and unobserved station characteristics that may be correlated with employment and with service configuration, as long as these variables are time invariant, but also restrict the identification of coefficients to the sample of stations observed more than once.

The results are given in Table 4. Estimates of α_f vary in the range of approximately 1–1.1 when station fixed effects are omitted, and fall to approximately 0.6 when station fixed effects are included. Estimates of α_s vary in the range of approximately 0.5–0.7 when station

[20]The taxonomy is from **?**.

fixed effects are omitted, and fall to approximately 0.4 when station fixed effects are included. The difference between the two is statistically significant in all specifications (test statistics omitted), and the ratio ranges from 1.4 (in specification 7) to 2.1 (in specification 6). Other variables have expected signs. For example, older stations tend to have more employees, all else equal; stations that belong to multi-unit firms generally have fewer employees; and stations with convenience stores and repair shops have more employees. Employment per dollar of revenue is several times higher for alcohol and repair services than it is for grocery items. Employment per dollar of tobacco revenue varies across specifications. Our most preferred specification is in column (8), in which we control for station, state, year, and state×year fixed effects, as well as all available station characteristics.

Gallons are reported with significant rounding error. If gallons were accurately reported, only 1% of observations would have values divisible by 100 and only 0.1% would have values divisible by 1,000. Instead, we find that 30% of observations report gallon sales divisible by 100, and more than 10% are divisible by 1,000. If rounding is symmetric, there is no bias in the reported variable but the estimated coefficients α_f and α_s are attenuated. We address this problem by instrumenting $\widetilde{G}$ with the number of pumps allocated to the same service level. These results are given in Table 5. As expected in the case of measurement error, the IV estimates of α_f and α_s are both larger than the OLS estimates. Again, they are statistically different from one another in every specification. The ratio ranges from 1.2 (in specification 7) to 2.1 (in specification 3).[21]

For a station converting from full service to self service while maintaining the same

[21] The conventional "rule-of-thumb" for sufficiently strong instruments in the case of one instrument is a first-stage F statistic of 10 (**?**). As there is no single F statistic for the case of multiple variables with multiple instruments, **?** offer a new test statistic, for which **?** provide critical values. The 10% critical value of the Cragg-Donald test statistic, which corresponds roughly to the Staiger-Stock rule of thumb, is 7.03 in the case of two mis-measured variables and two instruments. However, the Cragg-Donald test statistic assumes non-clustered standard errors. **?** provide an alternative test that is robust to clustered standard errors. The critical value of the Kleibergen-Paap test statistic is not known, so current practice uses the same critical value. We report the Cragg-Donald test statistic for all regressions, and the Kleibergen-Paap test statistic when possible.

physical capacity reduces the labor requirement to $\frac{\alpha_s}{\alpha_f}$, or approximately three quarters, of the full-service level. If we use our preferred estimates, the IV estimates in column (8), a station selling 700,000 gallons of gasoline per year would need four attendants for full service, but only three attendants if it operated by self service. The labor input of the fourth attendant is now provided by the customer, who is compensated with a lower price.

The price discount applied to self-service gasoline can provide a back-of-the-envelope check on our point estimates. A station operating both full-service and self-service pumps must be, on the margin, roughly indifferent between switching the marginal pump to self service or keeping it as a full-service pump. The cost of switching a pump to self service is the lost revenue from the full-service premium; the gain is the reduction in labor costs.

There are several estimates of the full-service premium. For 1987, **?** estimates the full-service premium in a four-county area in eastern Massachusetts at between seven and nine cents, in nominal 1987 dollars. Using her raw data, we find that, depending on the transaction type (cash or credit) and the gasoline type (regular or premium; leaded or unleaded) the average full-service premium ranges from 6% to 10%. For 1982, we use data from the Bureau of Labor Statistics (BLS) and the American Chamber of Commerce Research Association (ACCRA) to estimate the average full-service premium nationwide at around 7%, or about 11 cents in 1992 dollars. (Details of this estimation are in Appendix B.) From Table 2, gallons per pump range from an average of 75,000 (full-service gallons in mixed-service stations) to 151,000 (self-service gallons in self-service stations), delivering a broad range of estimates of the revenue loss from switching a pump from full to self service. If we use the average gallons per pump in a mixed-service station, 92,600, the cost of converting a pump to self service is an annual revenue loss of between \$5,740 and \$10,740.

For a pump dispensing 92,600 gallons per year, our estimates put the labor input for full service at $\left(\frac{\mu\widehat{\alpha}_f}{3120\eta\gamma}\cdot 92,600\right) = 0.525$ workers using our preferred estimate $\widehat{\alpha}_f = 1.579$ from column (8) of Table 5. If the pump is converted to self service, the labor input falls to $\left(\frac{\mu\widehat{\alpha}_s}{3120\eta\gamma}\cdot 92,600\right) = 0.405$ workers. The average annual wage for a gas-station worker in the CPS, in 1992 dollars, is about $14,000. So the labor-cost saving is approximately $(0.525 - 0.405) \cdot 14,000$, or $1,680.

The gap between the labor-cost saving and the revenue loss supports **?**'s (**?**) argument of price discrimination and, more broadly, strategic prices. Particularly as full-service stations become scarce, they may charge a premium to inelastic consumers of service above and beyond the cost of supplying this service. The fact that full-service stations virtually disappeared by the end of our sample period suggests that this price discrimination was not sustainable in the long run, however.

5 Productivity Measurement

Our results highlight several challenges in productivity measurement introduced by the increasing adoption of self-service in retail trade and by other organizational changes related to this adoption.

The literature on productivity measurement in manufacturing has distinguished between a revenue-based productivity measure (e.g., "revenue TFP," or TFPR) and physical-quantity-based productivity measure ("quantity TFP," or TPFQ). In the retail sector, where quantity is typically not measurable, all studies of which we are aware have used revenue-based measures of productivity (see, e.g., **???**). The standard measure of retail productivity is revenue per worker. In this sense gasoline retailing is unique, because sales volume, and not just revenue, is collected in the CRT. Moreover, the output of gasoline stations is relatively homogeneous and easy to measure, allowing us to compute a physical productivity measure using volume output: gallons per worker.[22]

However, neither measure is well suited to measure productivity in our setting. We consider the most common measure of productivity used in studies of the retail sector, revenue per worker $\left(\frac{\text{Revenue}}{\text{L}}\right)$, and a quantity-based measure, gallons per worker $\left(\frac{\text{G}}{\text{L}}\right)$.

[22] **?** calculate TFPQ for eleven homogeneous manufacturing products, including gasoline.

The main problem with these measures is that the labor input, L, includes only employee labor and not customer labor. Because the share of labor accounted for by customers has increased over time, the growth rate of productivity is biased upwards.[23]

A second issue common to both measures is the increase in the prevalence and size of convenience stores. This change has lead to an increase in the number of non-attendants, L_0 in our notation. Any measure of output per worker must account for the increase in L_0. We can sidestep this issue by calculating productivity only for stations with no convenience stores and repair shops, but the broader problem, that we are unable to observe production vs. non-production employment, remains, and is salient in any industry in which the product or service mix shifts over time.[24] This complication favors using revenue per worker, since convenience-store workers produce revenue even if they do not produce gasoline sales.

On the face of it, the revenue-based productivity measure has an additional advantage: the ratio of the full-service and self-service prices may reflect the relative productivities of the employees. So, as the denominator falls due to an increase share in the unmeasured labor input, the numerator also falls because the per-gallon price of self-service gasoline is lower than the price of full-service gasoline. Although this mitigates the bias, there is no reason to expect these two effects to cancel out. On the other hand, in our context the revenue-based productivity measure is problematic because the price of gasoline has swung dramatically over the years for reasons unrelated to retail productivity. Most notably, the price of crude oil rose more than threefold between 1977 and 1982. Crude-oil price fell by 1987, although not to 1977 levels. Any revenue-based measure of productivity that does not adjust for this fact would misrepresent 1982 as the high point of labor productivity. A secondary problem is that as gas stations have become larger, concentration in this industry has increased. Published County Business Patterns tables show that the average number of stations per

[23] This point is not new; **?**, p. 162 argues that the "theory of production has to be augmented by including the inputs of consumers and producers in measuring the rate of technical progress."

[24] L_0 may also change as the vertical structure of stations changes, as seen in the regression results in Tables 4 and 5.

county fell by 28%, from 44.3 to 31.8, between 1977 and 1992, and the number of counties served by fewer than three stations nearly doubled, from 158 to 300.[25] Increased market concentration can lead to higher prices, which would bias upwards the estimated growth in revenue-based productivity. Although the former issue can, in principle, be addressed by deflating retail prices by rack or crude-oil prices, addressing the latter issue would require station-level measures of market power and price elasticity.[26]

Formally, using the retail-gasoline production function specified in this paper, we can write revenue per worker as

$$\frac{\mathrm{Revenue}}{\mathrm{L}} = \frac{p_f \mathrm{G}_f + p_s \mathrm{G}_s + p_x \mathrm{X}}{\mathrm{L}_0 + \mathrm{L}_f + \mathrm{L}_s} = \frac{3120\eta\gamma}{\mu} \frac{\frac{p_f \mathrm{L}_f}{\alpha_f} + \frac{p_s \mathrm{L}_s}{\alpha_s}}{\mathrm{L}_0 + \mathrm{L}_f + \mathrm{L}_s} + \frac{p_x \mathrm{X}}{\mathrm{L}_0 + \mathrm{L}_f + \mathrm{L}_s} \tag{3}$$

where p_f and p_s are the prices, respectively, of full- and self-service gasoline, and $p_x\mathrm{X}$ is revenue from non-gasoline goods and services. For a station with no convenience store or repair service, $p_x\mathrm{X} = 0$. If L_0, which is unobserved, is small enough, revenue per worker represents a weighted average of revenue per effective unit of labor. To the extent that the full-service price premium $\frac{p_f}{p_s}$ is approximately equal to the worker-productivity ratio $\frac{\alpha_f}{\alpha_s}$, this measure has the advantage that it should not be spuriously affected by the transition from full service to self service. However, as shown in the previous section, the price ratio is about 1.07, whereas the productivity ratio we estimate is about 1.3.

Alternatively, gallons sold per worker is

$$\frac{\mathrm{G}}{\mathrm{L}} = \frac{\mathrm{G}_f + \mathrm{G}_s}{\mathrm{L}_0 + \mathrm{L}_f + \mathrm{L}_s} = \frac{3120\eta\gamma}{\mu} \frac{\frac{\mathrm{L}_f}{\alpha_f} + \frac{\mathrm{L}_s}{\alpha_s}}{\mathrm{L}_0 + \mathrm{L}_f + \mathrm{L}_s} \tag{4}$$

[25] Increased concentration in local markets was accompanied by increased concentration nationally. Published CRT tables show that the market share of the top four firms in SIC 554 rose from 5.4% in 1977 to 7.2% in 1992.

[26] In this context, **?** argues that a revenue measure of productivity is preferable to a physical measure of productivity when firms do not have market power but produce goods of differential quality, because the prices embedded in the revenue-based measure implicitly adjust for differences in quality across firms. For a related discussion, see also **?**.

which, ignoring the constant factor $\frac{3120\eta\gamma}{\mu}$, is a weighted average of the productivities of the three types of workers $(0, \frac{1}{\alpha_f}, \frac{1}{\alpha_s})$. Holding the productivity parameters constant, however, a shift in the production function from full service to self service will appear by this measure to have increased productivity. At the extreme, suppose that $L_0 = 0$ and that a station transitions from having only full-service pumps to having only self-service pumps; measured productivity increases from $\frac{1}{\alpha_f}$ to $\frac{1}{\alpha_s}$.

To see how the transition from full-service to self-service and the change in bundling from repair shop to convenience store physical productivity over time, we compute the log of gallons sold per worker using four samples. We first compare locations with self-service bans to locations without bans. As shown in Figure 1 and discussed in Section 3, while stations in most of the country adopted the self-service model, stations in New Jersey, Oregon, and municipalities with self-service bans in place serve as a quasi-exogenous control group that allows us to capture counterfactual productivity, in the absence of self-service pumps. In addition, we compare locations with convenience stores and/or repair shops to locations with neither to determine the difference that the labor input L_0 makes in productivity calculations.

Figure 3 shows gallons per employee (physical employee productivity) for each of the four samples — ban vs. no ban, and convenience/repair vs. "pure" gas station. Although the time series of these two graphs is noisy, measured physical productivity is higher in the samples that exclude convenience stores and repair shops, because those mechanically drive up the denominator L without a concomitant increase in the numerator G. In addition, also as expected, measured productivity is higher in locations without a self-service ban than in locations with a ban, because customer labor is omitted from the numerator L in the former.

Figure 4 repeats this analysis using revenue per worker. The most obvious difference between the figures is the spike in measured revenue productivity in 1982 due to high oil prices. With a couple of exceptions, the rank order of the four series is the same as in Figure 3. *Ceteris paribus*, measured productivity is higher in locations without convenience stores and repair shops despite the fact that revenue is included in the numerator. Likewise, measured productivity is lower in locations with a self-service ban, because the measured labor input omits customer labor.

We can get a ballpark estimate of the magnitude of this bias by calculating a counterfactual measure of physical output. We hold stations' full-service gallons sold at actual values, but deflate the actual number of self-service gallons sold by 23% (the difference between $\hat{\alpha}_s$ and $\hat{\alpha}_f$ in column (8) of Table 5). This adjustment effectively forces the same level of physical output per employee in full- and self-service pumps. We calculate the ratio of adjusted gallons sold (full-service gallons plus 77% of self-service gallons) to actual employment. We think of this measure as physical *worker* productivity, in contrast with physical *employee* productivity, which we calculate directly from the data. Figure 5 shows average physical employee and worker productivity for stations not subject to a self-service ban which did not operate convenience stores or repair shops. In 1977, the two series differ by 7.5%; the average productivity level of stations subject to the ban (shown in Figure 3) lies between the two. By 1992, as the share of gasoline sold through self-service pumps increases, the gap between the two series increases to 20%. In other words, customer-employee substitution results in a 12.5% inflation in measured physical worker productivity.

This exercise illustrates the problem of reconciling naïve productivity measures with productivity parameters that come from understanding the production function. As highlighted in prior research, revenue productivity is sensitive to price changes, whether due to changes in market power or, in our case, to macroeconomic conditions. Physical productivity comes closer to measuring the theoretical ideal, but, as Figure 3 illustrates, gallons per worker and gallons per *employee* diverge in an environment in which some of the work is performed by customers.

6 Concluding Remarks

Customers have always belonged in the retailer's production function: without them, the store "could not produce a transaction which is the raison d'être for its existence" (**?**, p. 168).[27] The customer is unique among the inputs in that she is unpaid, or paid implicitly, for example in the form of lower prices or increased convenience. The gas-station sector highlights some of the strengths and weaknesses of both physical and revenue measures of productivity. As more businesses adopt self-service technology, addressing these measurement issues becomes increasingly important for understanding productivity dynamics.

The trend of increasingly incorporating customers into the production function has been going on for many decades, starting with Piggly Wiggly's first "self-service" grocery store in 1916 (**?**) and continuing through the elimination of telephone and elevator operators. There is some evidence to suggest that these new customer-workers become invested in the product or service they perform, and experience an increase in utility despite the effort cost involved (**?**).

A parallel but opposite problem occurs in industries that offer increased services, such as prepared packaged foods and delivery services that save consumers the need to go to the grocery store, select, and carry home their groceries. In these cases, workers are performing tasks previously done by households. In another guise, this problem is much older: the shift of manufacturing, such as weaving, from the household to dedicated manufacturing establishments (**?**).

The effects of customer-employee substitution are complex and transformative. Employment by gasoline stations has increased despite a labor saving of approximately 0.4 workers per pump in part because self-service adoption induced a change in the business model: stations increased in size, divested themselves of repair shops, added convenience stores, and

[27] The employee, in contrast, may be expendable: **?** document the advent of fully automated, zero-employee, gas stations in the Netherlands.

increased their hours of operation. These changes likely transformed the skill set of workers as they have taken on new tasks. **?** similarly attributes the preservation of teller jobs to changes in banks' underlying business model. As the number of tellers required per branch fell, banks responded by opening more branches and those tellers that remained became part of the "'relationship' banking team" (p. 17). An exciting development in self-service is currently being played out in drugstores where we see the rise in self-checkout with the simultaneous rise in the provision of health services. It remains to be seen whether similar transformations will take place in other sectors that are increasingly utilizing customer labor for tasks previously performed by paid employees.

A Data

A.1 Auxiliary Data

Data on local self-service bans come from a variety of sources, mostly media mentions, which we have made every effort to verify using city bylaws and regulations. We use an indicator for a city or state's ban on self service as an instrument for self-service adoption. The main bans, in New Jersey and Oregon, have been in place the entire study period (and remain in place in 2017). Local bans are also in place in four Massachusetts cities (Arlington, Holbrook, Weymouth, and Upton) and in Huntington, NY. Two other New York towns, East Hampton and the Village of Patchogue, repealed their bans in the late 1980s. Although we have spent considerable time combing through township statutes, particularly in New York and Massachusetts, to determine when and where self-service bans have been in place, we make no claims about the completeness of our list of city-level bans, particularly not historically.[28]

Data on the effective minimum wage in each state for 1979–1992 come from **?**. For earlier data we rely on the appendix to **?** and on **?**. Because the rest of our data are annual, if the minimum wage changes during the year, we take a weighted average of the applicable rates. The federal minimum wage was \$2.30 in 1977 (\$5.39 in 1992 dollars), \$3.35 in 1982 and 1987 (\$4.93 and \$4.18 in 1992 dollars, respectively), and \$4.25 in 1992. As **?** has noted, there is not nearly as much variation in state-level minimum wages during this early period: 45 states used the federal minimum in 1977, 48 states and the District of Columbia used it in 1982, and 43 states and DC in 1987 and 1992. Over the years, a total of 12 states and the District of Columbia deviated from the federal minimum in one or more years: Alaska and Connecticut (all four years); Hawaii, New Jersey, and Rhode Island (each in two of the four years); and California, DC, Iowa, Massachusetts, Maine, Oregon, and Vermont each in

[28]Many towns have additional regulations during part or all of the study period, most commonly requiring an attendant on duty during operating hours even at self-service stations. Because these regulations are very local and often changed over time, it is impossible to fully account for them in a national study such as this one.

one year.

We use the Current Population Survey's Merged Outgoing Rotation Groups (CPS-MORG) from the 1979–1992 waves to calculate average hours worked per gas-station attendant. Gas stations are identified using 1970 industry code 648 and 1980 industry code 621; attendants are identified using 1970 occupation code 623 or 1980 occupation code 885. These data are not matched to the CRT. Although the CPS sample is not intended to be representative within narrow industry and occupation classifications, it is nonetheless telling that, among CPS respondents in the gas-station sector, the fraction who gave their occupation as attendants declined steadily between 1979 and 1992, from about 46% to 27%.[29] Gas-station workers who reported their average weekly pay earned approximately $270 per week in 1992 dollars (averaged across all workers, regardless of number of hours worked), which translates to about $14,000 over 52 weeks.

We use two external data price series, one from the Bureau of Labor Statistics (BLS) and the other from the American Chamber of Commerce Research Association, or ACCRA (today, the Council for Community and Economic Research, or C2ER), to estimate the full-service premium in 1982.[30]

The BLS published a price series for "gasoline, unleaded regular, per gallon" including relevant excise taxes starting in 1976. The BLS price series does not specify a service level, and averages out both full-service and self-service outlets surveyed. (The series also combines cash and credit prices.) Because, as documented in this paper, almost all stations sold full-service gasoline only at the beginning of the series, and over time more and more switched to the self-service model, the series likely represents a slow-moving weighted average of the full- and self-service prices.

ACCRA has published a quarterly cost-of-living index and component prices of several

[29] In New Jersey and Oregon the share of gas-station workers — a small sample — describing themselves as attendants increased from 43% to 60% over this period.

[30] These data have been used in numerous papers, including **?** and **?**.

dozen products and services since 1968. Over the period 1976–1992, between 165 and 300 cities were included in the survey in any given quarter. Volunteers collected prices in the first week of every quarter (in January, April, July, and October) and were instructed to sample at least five outlets if possible and report the average price. The ACCRA product description for gasoline changed a few times over this period. At first, the product definition was simply "gasoline: regular grade, including taxes (national brand)." Starting in the fourth quarter of 1976, the product definition was revised to add the term "full service," evidence of the increasing adoption of the self-service model throughout the 1970s. In 1979Q2, the word "unleaded" was added to modify "regular grade." In 1982Q1, "full service" was replaced with "self service if available." Finally, in 1986Q1, ACCRA for the first time specified "cash price."

A.2 CRT Data Quality

We have merged the 1987 CRT observations from four counties in Massachusetts (Essex, Middlesex, Norfolk, and Suffolk) with data provided by the Lundberg survey from the first three months of 1987. The Lundberg data, which have been used by **??** and **??**, include prices at over 1,500 gas stations in these four counties. Up to 16 prices are provided for each station, representing combinations of four binary variables: full vs. self service; cash vs. credit; leaded vs. unleaded gasoline; and regular vs. premium gasoline. We code any station that posts at least one self-service price as offering self service. We then match the data with the CRT, merging on name and address. Of the 900 stations we successfully merge across the two datasets, a third (300) have complete data in the 1987 CRT.[31] Of these, over 95% of stations that report having self-service pumps in the CRT are also recorded as having one or more self-service prices in the Lundberg file, and over 85% of stations that report not having self-service pumps in the CRT also have no self-service prices in the Lundberg file.

[31] All observation counts are rounded to the nearest hundred.

Considering the timing is slightly different in the two datasets (the CRT is conducted at the end of the year, and the Lundberg surveys took place in the first quarter), we consider this match level very high.

B Self-Service vs. Full-Service Prices

We exploit the abrupt transition from "full service" to "self service" in the ACCRA price series in contrast with the gradual transition in the BLS series to uncover the full-service price premium. (The data are described in Appendix A.) The BLS price for the average U.S. city and the average reported ACCRA price are shown, at quarterly frequency, in the top panel of Figure B-1. The first vertical line, between the first and second quarter of 1979, separates the earlier period, during which the ACCRA prices may have been for leaded gasoline, with the later period, during which unleaded was specified. The second vertical line, between the last quarter of 1981 and the first quarter of 1982, marks the change from full-service to self-service prices. The bottom panel in Figure B-1 shows the ratio of the two series.

Prior to the second quarter of 1979, the ratio of the BLS price to the average ACCRA price, representing the "unleaded premium" in the BLS price, ranges from two to six percent, with an average of about four percent. Once "unleaded" is specified by ACCRA, the two series move together very closely: for five consecutive quarters, the ratio is almost exactly 1. Then, in the third quarter of 1980, the ACCRA series starts breaking away from the BLS series, and the ratio starts falling, eventually reaching 0.96. This trend is abruptly broken when ACCRA switches from full-service to self-service gasoline; for the next three years, the BLS price is about 3% higher than the ACCRA price.[32]

[32] Because the ACCRA sample is time-varying, we confirm that the break between 1981Q4 and 1982Q1 is not due to a change in the sample. Excluding cities in New Jersey and Oregon (of which there are too few to form a meaningful separate sample), there are 227 cities in the 1981Q4 sample and 206 in the 1982Q1 sample; the two samples overlap for 189 cities in 41 states.

We infer the self-service discount (full-service premium) in 1982Q1 is about 7%.

As the gap between the two series closes, the two prices are once again indistinguishable by mid-1989. This need not reflect a diminishment in the full-service premium, however; over time, the BLS price includes more and more self-service outlets as the self-service model spreads, mechanically moving the BLS price towards the ACCRA price.

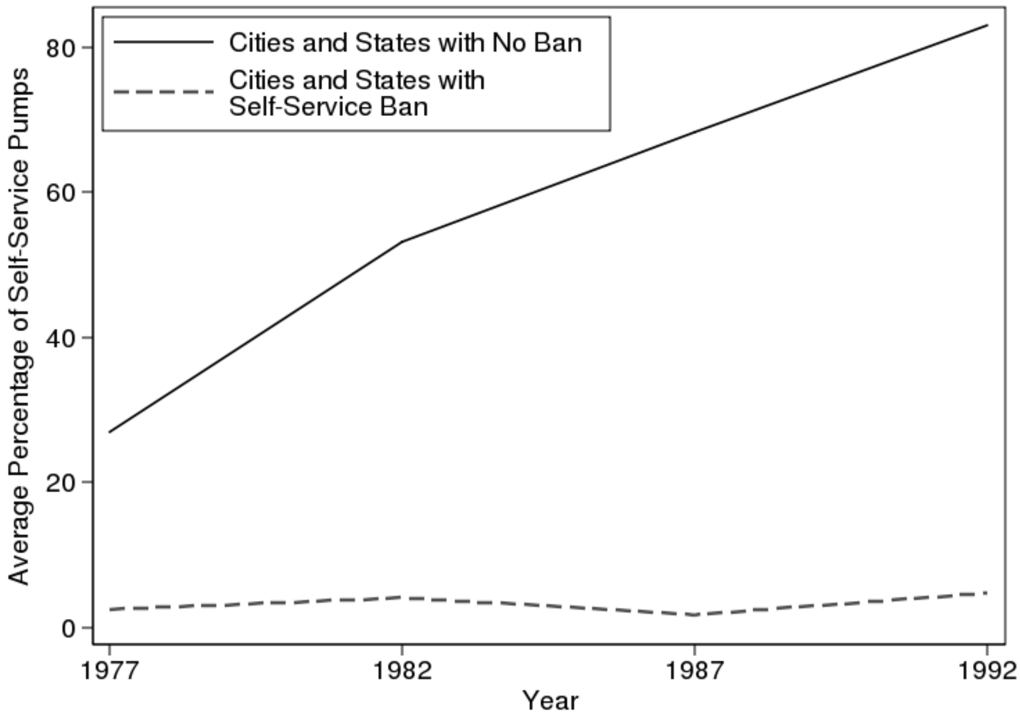


Figure 1. Self-Service Adoption Rates in Locations with and without Self-Service Bans

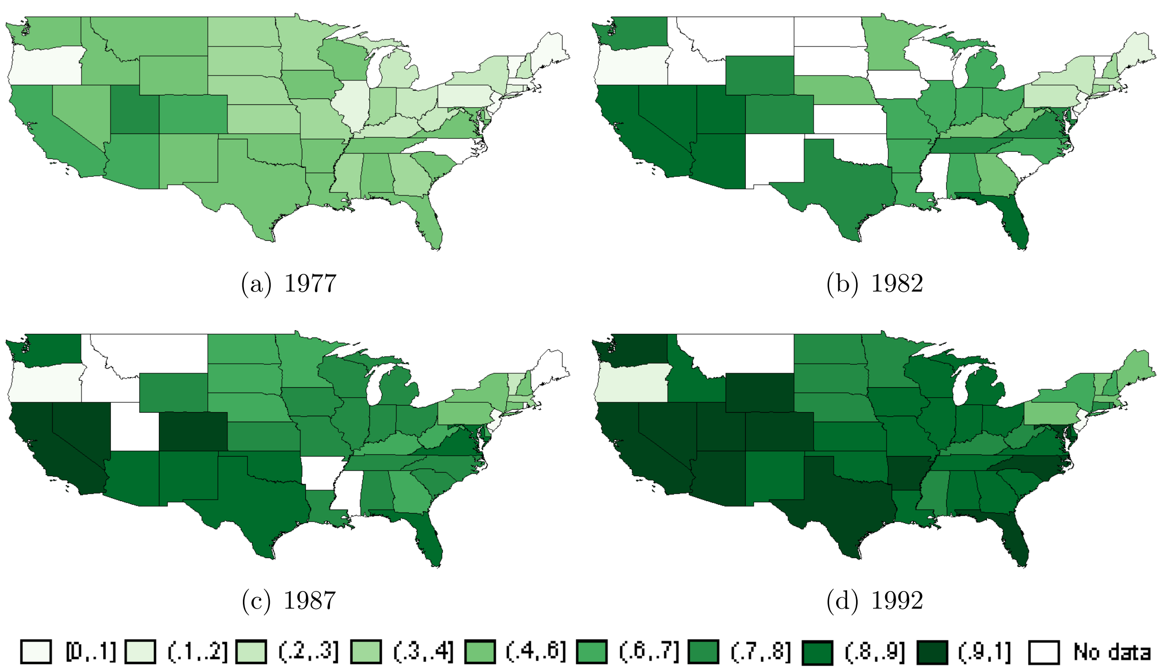


Figure 2. Fraction of Stations Offering Self Service, by State
Source: Published CRT tables

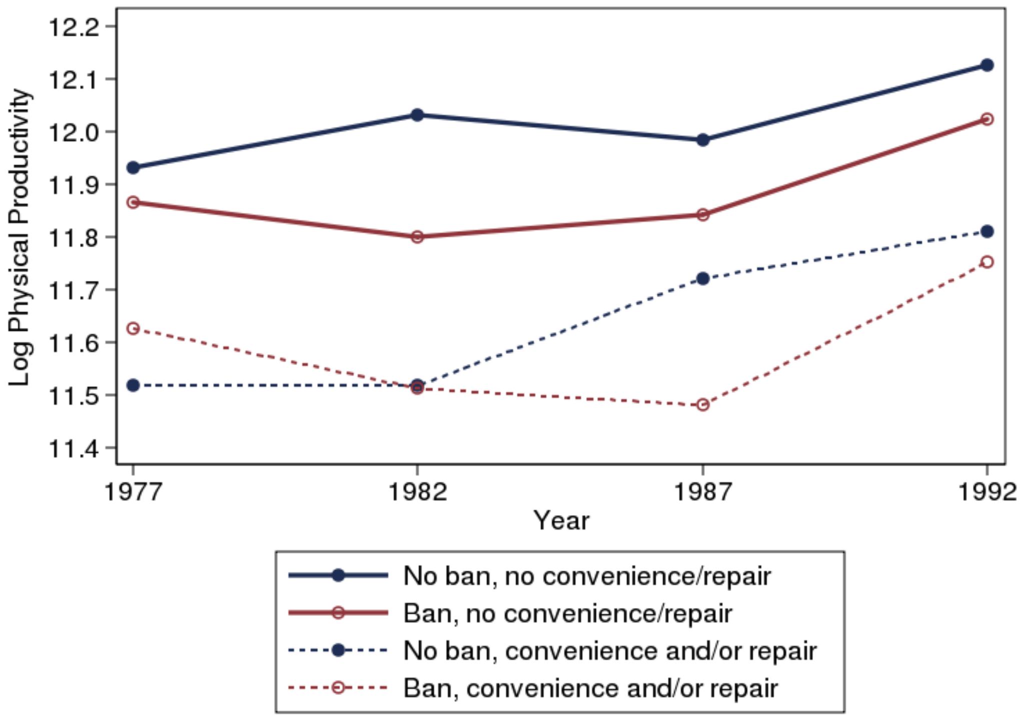


Figure 3. Physical Productivity

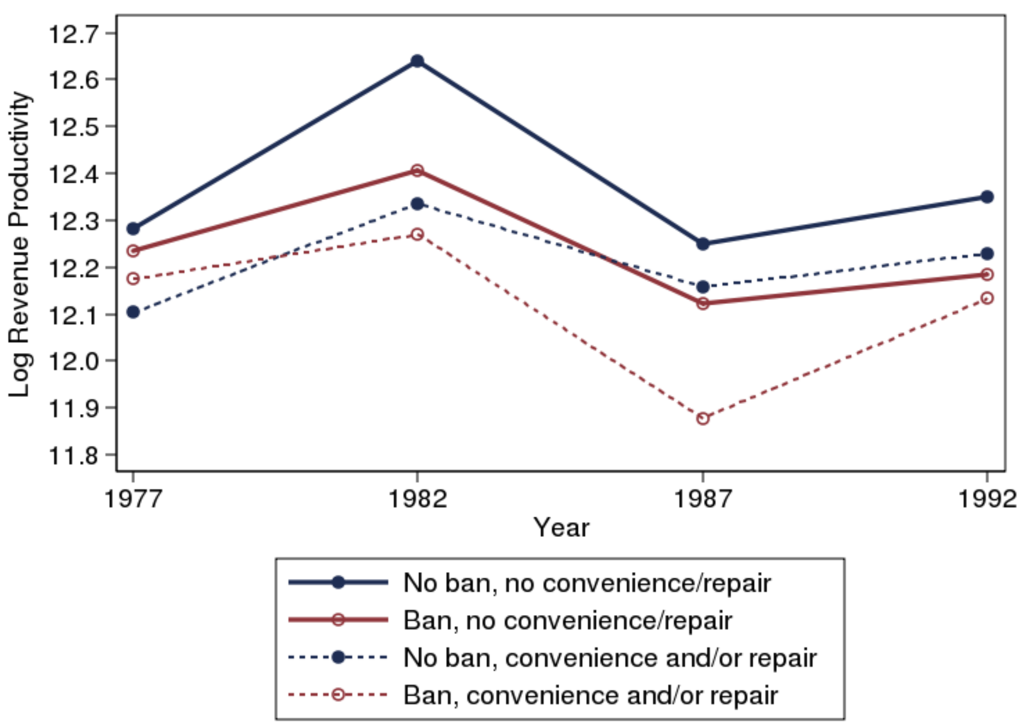
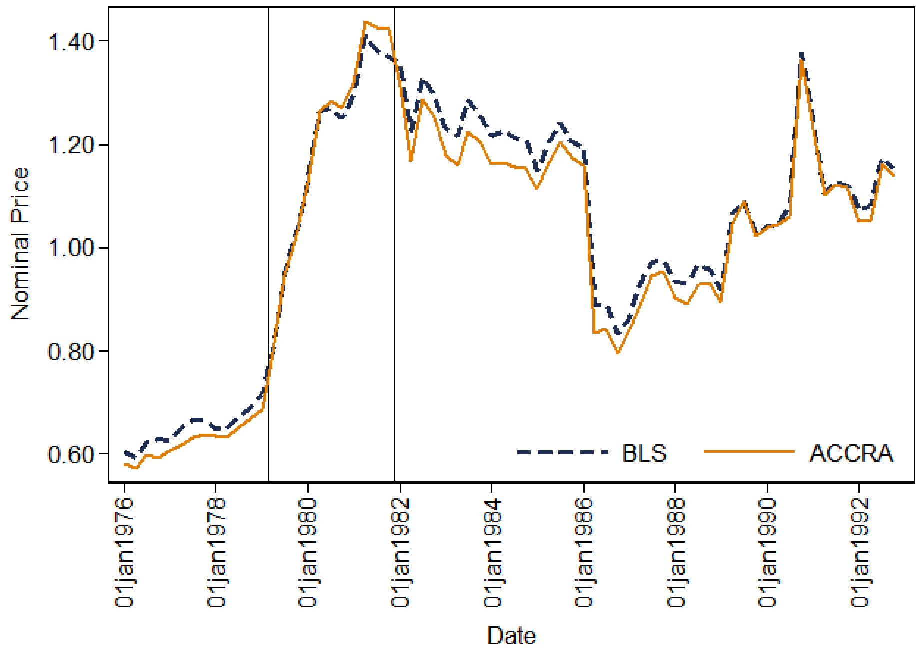
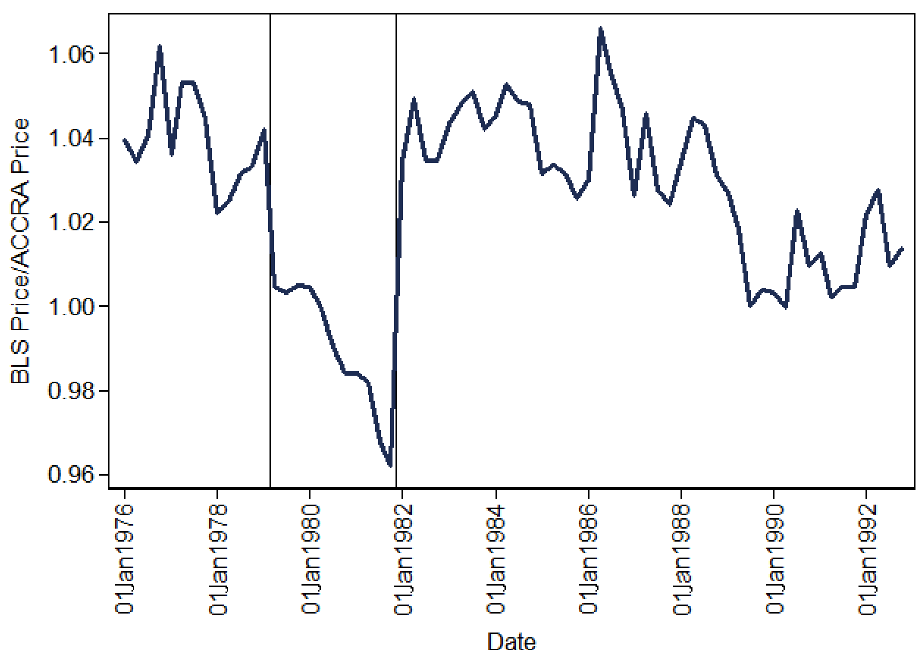


Figure 4. Revenue Productivity

Figure 5. Physical Employee Productivity vs. Physical Worker Productivity
Stations with no ban and no convenience/repair



(a) Nominal BLS and ACCRA prices



(b) Price Ratio

Figure B-1. BLS and ACCRA Average Nominal Prices for Gasoline

Table 1. Trends in the Gas-Station Sector, 1972–1997

	1972	1977	1982	1987	1992	1997
Gas stations (SIC 554)	183,385	146,523	116,188	114,748	105,334	98,846
Convenience stores selling gas (SIC 541130)	n/a	5,138	13,390	20,293	23,065	28,043
All locations selling gas	n/a	151,661	129,578	135,041	128,339	126,889
Employment at gas stations (SIC 554)	747,668	672,673	603,886	701,690	675,080	741,040
Employment at convenience stores selling gas (SIC 541130)	n/a	48,627	94,670	148,499	142,183	181,022
Total employment at locations selling gas	n/a	721,300	698,556	850,189	817,263	922,062
Average station employment (SIC 554)	4.1	4.6	5.2	6.2	6.4	7.5
Average station employment (SIC 541130)	n/a	9.5	7.1	7.3	6.2	6.5
Self service (% of stations)[a]	8.2	38.3	58.7	70.5	79.9	n/a

Source: Authors' calculations from published and unpublished CRT data
Figures refer to stations with payroll
[a] SIC 554 only

Table 2. Summary Statistics for Micro Data

	All Stations	Full Service	Self Service	Mixed Service
Stations (#)[a]	109,300	45,800	40,400	33,300
Observations (#)[a]	152,700	54,500	56,400	41,800
Average employment	6.2	5.4	6.2	7.3
Age$\geq$ 2 (%)	90.4	92.2	87.2	92.3
Multi-unit firm (%)	54.5	33.1	90.9	33.5
Vertically integrated (%)	25.5	14.7	46.2	11.8
Average number of pumps:				
All pumps	7.8	5.8	8.8	9.1
Full-service pumps	3.2	5.8	–	4.1
Self-service pumps	4.6	–	8.8	5.0
Average gallons sold (000s):				
All gallons	830.6	580.8	1,118.3	768.5
Full-service gallons	283.1	580.8	–	276.9
Self-service gallons	547.5	–	1,118.3	491.6
Gallons per pump (000s):				
All gallons	118.8	105.5	151.1	92.6
Full-service gallons	92.2	105.5	–	75.0
Self-service gallons	132.5	–	151.1	107.4
Convenience store (%)	45.9	22.4	72.8	40.3
Repair shop (%)	41.7	56.2	4.3	73.0

[a] Station and observation counts rounded to the nearest 100 to minimize disclosure risk

Table 3. Self-Service Adoption Intensity: OLS Estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(Pumps)	0.130***	0.106***	0.100***	0.034***	0.131***	0.106***	0.100***	0.037***
	(0.012)	(0.008)	(0.007)	(0.006)	(0.012)	(0.008)	(0.007)	(0.006)
Age$\geq$ 2	-0.038***	-0.038***	-0.035***	-0.006	-0.046***	-0.045***	-0.043***	-0.010
	(0.010)	(0.010)	(0.010)	(0.017)	(0.009)	(0.009)	(0.009)	(0.018)
Multi-unit firm	0.178***	0.170***	0.168***	0.052***	0.248***	0.238***	0.237***	0.058***
	(0.016)	(0.012)	(0.011)	(0.012)	(0.016)	(0.015)	(0.015)	(0.012)
Vertically integrated	0.048***	0.063***	0.061***	-0.016	0.061***	0.078***	0.076***	-0.019
	(0.015)	(0.012)	(0.013)	(0.030)	(0.016)	(0.011)	(0.011)	(0.028)
Convenience store	0.154***	0.130***	0.126***	0.019				
	(0.017)	(0.011)	(0.011)	(0.014)				
Repair shop	-0.163***	-0.162***	-0.163***	-0.112***				
	(0.019)	(0.017)	(0.016)	(0.012)				
Grocery revenue[a]					0.483***	0.526***	0.515***	0.195***
					(0.060)	(0.058)	(0.057)	(0.037)
Alcohol revenue[a]					0.416***	0.369***	0.376***	0.526***
					(0.113)	(0.105)	(0.116)	(0.100)
Tobacco revenue[a]					0.791***	0.437***	0.398***	0.213
					(0.106)	(0.076)	(0.085)	(0.146)
Repair revenue[a]					-0.488***	-0.451***	-0.472***	-0.096**
					(0.090)	(0.069)	(0.059)	(0.039)
ln(Stations)	0.009	0.014***	-0.040**	-0.059***	0.007	0.013***	-0.065***	-0.062***
	(0.007)	(0.003)	(0.017)	(0.021)	(0.007)	(0.003)	(0.018)	(0.022)
ln(Minimum wage)	1.042*	0.486**	0.485**	0.535**	0.821	0.340*	0.342*	0.483**
	(0.579)	(0.208)	(0.202)	(0.239)	(0.562)	(0.191)	(0.186)	(0.220)
Year= 1982	0.305***	0.253***	0.242***	0.261***	0.299***	0.253***	0.236***	0.254***
	(0.067)	(0.032)	(0.031)	(0.036)	(0.065	(0.032)	(0.030)	(0.035)
Year= 1987	0.504***	0.375***	0.362***	0.381***	0.484***	0.366***	0.348***	0.365***
	(0.161)	(0.062)	(0.060)	(0.070)	(0.157	(0.059)	(0.057)	(0.064)
Year= 1992	0.563***	0.447***	0.430***	0.429***	0.549***	0.443***	0.419***	0.419***
	(0.144)	(0.059)	(0.057)	(0.065)	(0.141	(0.058)	(0.055)	(0.061)
State FE		✓	✓	✓		✓	✓	✓
County FE			✓	✓			✓	✓
Station FE				✓				✓

All regressions have 146,400 observations (omits stations subject to self-service bans).
* p<10%; ** p<5%; *** p<1%. Standard errors are clustered by state.
[a] Revenue in millions of 1992 dollars

Table 4. Productivity Parameters: OLS Estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\widetilde{G}^f$	1.040***	1.091***	1.092***	1.121***	1.152***	1.069***	0.637***	0.608***
	(0.021)	(0.023)	(0.023)	(0.024)	(0.024)	(0.022)	(0.032)	(0.031)
$\widetilde{G}^s$	0.713***	0.574***	0.573***	0.662***	0.688***	0.516***	0.442***	0.364***
	(0.013)	(0.013)	(0.014)	(0.016)	(0.016)	(0.013)	(0.025)	(0.023)
Age≥ 2				0.391***	0.384***	0.309***	0.920***	0.814***
				(0.044)	(0.044)	(0.042)	(0.078)	(0.076)
Multi-unit firm				-1.197***	-0.428***	-0.339***	-0.961***	-0.789***
				(0.038)	(0.045)	(0.038)	(0.268)	(0.259)
Vertically integrated				0.027	0.078*	0.346***	-0.020	-0.124
				(0.042)	(0.041)	(0.038)	(0.090)	(0.087)
Convenience store					0.897***		0.396***	
					(0.030)		(0.044)	
Repair shop					1.600***		0.637***	
					(0.041)		(0.096)	
Grocery revenue[a]						7.817***		3.410***
						(0.207)		(0.380)
Alcohol revenue[a]						25.518***		10.694***
						(1.185)		(0.931)
Tobacco revenue[a]						5.755***		9.908***
						(0.491)		(0.768)
Repair revenue[a]						29.938***		13.299***
						(0.499)		(1.084)
Year FE		✓	✓	✓	✓	✓	✓	✓
State FE		✓	✓	✓	✓	✓	✓	✓
State*Year FE			✓	✓	✓	✓	✓	✓
Station FE							✓	✓

All regressions have 152,700 observations. LHS variable is station employment.
* p<10%; ** p<5%; *** p<1%. Standard errors are clustered by station.
$\widetilde{G}^f$ and $\widetilde{G}^s$ are full- and self-service gallons, adjusted for part-year operations and divided by 278,460
[a] Revenue in millions of 1992 dollars

Table 5. Productivity Parameters: IV Estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\widetilde{G}^f$	2.438***	2.578***	2.614***	2.397***	2.274***	2.150***	1.606***	1.579***
	(0.044)	(0.023)	(0.023)	(0.021)	(0.020)	(0.019)	(0.099)	(0.098)
$\widetilde{G}^s$	1.407***	1.219***	1.222***	1.385***	1.391***	1.157***	1.287***	1.217***
	(0.022)	(0.013)	(0.013)	(0.014)	(0.014)	(0.014)	(0.085)	(0.085)
Age$\geq$ 2				0.186***	0.193***	0.147***	0.437***	0.383***
				(0.043)	(0.042)	(0.039)	(0.094)	(0.090)
Multi-unit firm				-1.814***	-0.710***	-0.882***	-0.855***	-0.734***
				(0.034)	(0.036)	(0.032)	(0.261)	(0.256)
Vertically integrated				-0.798***	-0.684***	-0.403***	0.139	0.027
				(0.039)	(0.038)	(0.036)	(0.106)	(0.104)
Convenience store					0.729***		0.147***	
					(0.030)		(0.052)	
Repair shop					2.132***		1.058***	
					(0.034)		(0.112)	
Grocery revenue[a]						5.686***		0.264
						(0.145)		(0.502)
Alcohol revenue[a]						23.339***		7.230***
						(0.376)		(1.021)
Tobacco revenue[a]						5.961***		8.932***
						(0.325)		(0.817)
Repair revenue[a]						28.120***		11.751***
						(0.243)		(1.071)
Cragg-Donald test statistic	16,067	14,018	13,861	14,762	15,491	14,257	898	890
Kleibergen-Paap test statistic	2,715						386	390
Year FE		✓	✓	✓	✓	✓	✓	✓
State FE		✓	✓	✓	✓	✓	✓	✓
State*Year FE			✓	✓	✓	✓	✓	✓
Station FE							✓	✓

All regressions have 152,700 observations. LHS variable is station employment. Gallons are instrumented by pumps.

* $p<10\%$; ** $p<5\%$; *** $p<1\%$. Standard errors are clustered by station.

$\widetilde{G}^f$ and $\widetilde{G}^s$ are full- and self-service gallons, adjusted for part-year operations and divided by 278,460

[a] Revenue in millions of 1992 dollars