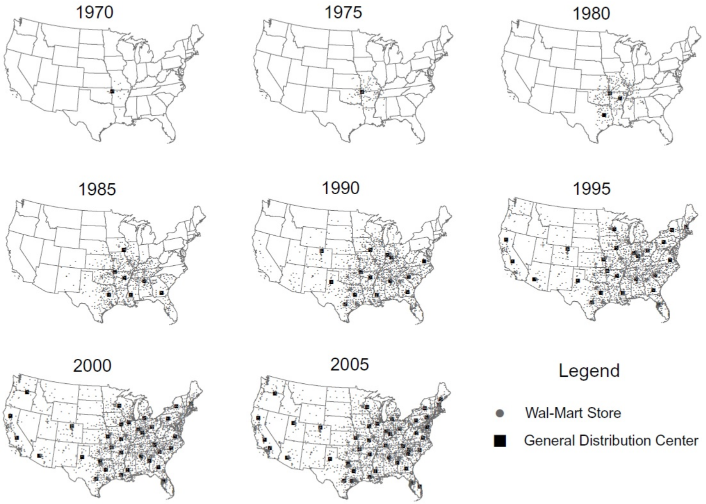
The Diffusion of Wal-Mart and the Economies of Density

Thomas J. Homes (2011)

Wal-mart

- Wal-Mart is an American multinational retail corporation that operates a chain of hypermarkets, discount department stores, and grocery stores, headquartered in Bentonville, Arkansas.
- The company was founded by Sam Walton in 1962
- As of October 31, 2020, Walmart has 11,510 stores and clubs in 27 countries, operating under 56 different names.
- Wal-Mart is vertically integrated into distribution: general merchandise is supplied by Wal-Mart's own regional distribution centers, groceries for super-centers through its own food distribution centers.
- The paper studies the U.S. expansion strategy of Walmart during from 1962-2005.

Diffusion of Wal-Mart stores and general distribution centers.



Wal-Mart's Strategy

- The new store openings radiated from the inside out, placing new stores close to where it already had store density.
- This process was repeated in 1988 when Wal-Mart introduced the supercenter format.
- Walmart has heavily invested in the late 1980s in the company's satellite network, linking all stores with two-way voice and data transmissions and one-way video communications with the Bentonville office.
- At the time, the company was the largest private satellite network, allowing the corporate office to track inventory and sales and to instantly communicate to stores.
- Walmart was more profitable than it's competitors (K-Mart, Sears). By 1990, it became the largest U.S. retailer by revenue.
- In the 1990s Walmart stores opened throughout the rest of the U.S., with Vermont being the last state to get a store in 1995.

Pros and cons of Wal-Mart's diffusion strategy

- Pros:
  - When stores are packed closely together, it is easier to set up a distribution network that keeps stores close to a distribution center, so Wal-Mart can save on trucking costs.
  - Maybe more importantly, such proximity allows Wal-Mart to respond quickly to demand shocks.
- Cons:
  - The market areas of different stores overlap, and new stores cannibalize sales from existing stores.
  - The speed of national expansion may be delayed, i.e. profitable markets may not be served.

The Purpose of the Paper

- The roll-out of Wal-Mart store openings followed a pattern that radiated from the center outward, with Wal-Mart maintaining high store density and a contiguous store network all along the way.
- The paper estimates the benefits of such a strategy to Wal-Mart
- It focuses on the savings in distribution costs afforded by a dense network of stores.

The Intuition behind the Estimation Approach

- The paper estimates a standard demand model in which consumers choose among all the Wal-Mart stores in the general area where they live.
- The demand model can be used to derive store level revenues.
- It then develops and estimates a dynamic discrete choice model of how Wal-Mart rolled out its stores during the period 1962-2005.
- Computing the optimal decision rule for the discrete choice model is not feasible.
- Hence, the paper considers a perturbation approach that considers deviations from the observed policy which is treated as optimal.
- This gives rise to a set of moment inequality conditions, i.e. profits have to be lower if we deviate from the optimal policy.
- Identification is partial, i.e., there is a set of points satisfying the moment inequalities, rather than just a single point.

Main Results

- The estimates show the benefits to Wal-Mart of high store density are substantial.
- These benefits extend significantly beyond savings in trucking costs
- The paper estimates that when a Wal-Mart store is closer by one mile to a distribution center, over the course of a year, Wal-Mart enjoys a benefit that lies in a tight interval around $3,500.
- Given the many miles involved in Wal-Mart's operations and its thousands of stores, the estimate implies that economies of density are a substantial component of Wal-Mart profitability.

Data

- AC Nielsen: store level sales, employment, openings and closings.
- US Census: demographic data, local wages, and local rents.
- Walmart's annual reports: extent of cannibalization of sales of existing stores in the Management Discussion section of the reports.

Goods and Stores

- There are two categories of merchandise:
  1. general merchandise (g),
  2. food (f).
- There are two kinds of Wal-Mart stores:
  1. a regular store sells only general merchandise;
  2. a super-center sells both general merchandise and food;

Locations and Distance

- There is a finite set of location in the economy ($\ell = 1 \ldots L$).
- $d_{ll'}$: denotes the distance in miles between any given pair of locations l and l'
- B_t^{Wal}: denotes the set of locations that have a Wal-Mart at time t.
- $B_t^{Super} \subseteq B_t^{Wal}$ denotes the set of locations that have a super-center.

Revenues

- $R^g_{jt}(B^{Wal}_t)$: the general merchandise sales revenue of store j at time t given the set of Wal-Mart stores open at time t.
- $R^f_{jt}(B^{Super}_t)$: the food merchandise sales revenue of store j at time t given the set of Wal-Mart super stores open at time t.
- The paper assumes Wal-Mart sets constant prices across all stores and over time, i.e. no price variation across stores or time.
- $\mu\ R^g_{jt}(B^{Wal}_t)$ sales receipts less the cost for goods sold for general merchandise, where μ is the gross margin.

Distribution Costs

Each store requires distribution services. General merchandise is supplied by a general distribution center and food is supplied by a food distribution center. These distribution costs are given by:

$$DistributionCosts_{jt} = \tau \, d^g_{jt} + \tau \, d^f_{jt}$$

where:

- d^g_{jt}: the distance in miles from store j to the closest distribution center at time t and analogously for supercenters.
- τ: cost per mile per period per merchandise segment of servicing this store. (constrained to be equal across f and g)
- The distribution is a fixed cost that does not depend on the volume of store sales (really?).

Variable Costs

Assume that the variable input requirements at store j are all proportionate to sales volume R_j :

$$\begin{aligned} Labor_j &= \nu^{Labor} R_j \\ Land_j &= \nu^{Land} R_j \\ Other_j &= \nu^{Other} R_j \end{aligned}$$

Wages and land prices vary across locations and across time. Other consists of everything left out so far that varies with sales, including the rental on structure and equipment in the store (the shelving, the cash registers, etc.). The other cost component of variable costs is assumed to be the same across locations and the price is normalized to 1.

Fixed Costs

- We need to capture differences in fixed costs that vary across locations.
- Urban locations have disadvantages compared to non-urban locations: e.g. higher land rents, higher wages, inconvenient highway access.
- To capture potential disadvantages of urban locations, the fixed cost of operating j is given by

$$c(Popden_j) = \omega_0 + \omega_1 ln(Popden_j) + \omega_2 ln(Popden_j)^2$$

- The paper makes that $\omega_0 = 0$ since that parameter is not identified and does not affect the moment inequalities.

Locational Dynamics

In principle there are number of questions that one could answer:

- How many new Wal-Marts and how many new super-centers to open, and where to locate them?
- How many new distribution centers to open and where to located them?

The paper focuses on the first question treating the expansion and location of the distribution centers as exogenous.

Controls

- The sequence $a = (A_1^{Wal}, A_1^{Super}, A_2^{Wal}, A_2^{Super}, \ldots)$ specifies the locations of the new stores opened in each period t.
- Hence we have
$$B_t^{Wal} = B_{t-1}^{Wal} \cup A_t^{Wal}$$
where A_t^{Wal} is the set of new stores opened in period t.
- Similarly, we have
$$B_t^{Super} = B_{t-1}^{Super} \cup A_t^{Super}$$
where A_t^{Super} is the set of new superstores opened in period t.

The Expansion Problem

Wal-Mart's problem at time 0 is to pick a feasible a to maximize:

$$\max_a (\rho_t \beta)^{t-1} \sum_{t=1}^{\infty} \Big[\sum_{j \in B_t^{Wal}} [\pi_{jt}^g - c_{jt}^g - \tau d_{jt}^g] + \sum_{j \in B_t^{Super}} [\pi_{jt}^f - c_{jt}^f - \tau d_{jt}^f] \Big]$$

where

- the operating profits for a merchandise segment $e \in \{g, f\}$ at store j in time t are

$$\pi_{jt}^e = \mu R_{jt}^e - Wage_{jt} Labor_{jt}^e - Rent_{jt} Land_{jt}^e - Other_{jt}^e$$

- ρ_t captures the exogenous productivity growth of Wal-Mart.

Demand Specification

- A consumer at location ℓ chooses between shopping at the outside option and shopping at any Wal-Mart located within 25 miles.
  The choice set:

$$\bar{B}_{\ell}^{Wal} = \{j, j \in B^{Wal} \text{ and } Distance_{lj} \leq 25\}$$

- Utility if consumer chooses outside alternative 0:

$$u_0 = b(Popden_l) + LocationChar_l \alpha + \epsilon_0$$

where,

$$b(Popden) = \alpha_0 + \alpha_1 ln(\underline{Popden}) + \alpha_2 (ln(\underline{Popden}))^2,$$

and

$$\underline{Popden} = max\{1, Popden\}$$

units of density measure = thousands of people within five-mile radius

Demand Specification

Utility of buying at a Wal-Mart $j \in \bar{B}_l^{Wal}$:

$$u_{lj} = -h(Popden_l)Distance_{lj} + StoreChar_j\gamma + \epsilon_j$$

where,

$$h(Popden) = \zeta_0 + \zeta_1 ln(\underline{Popden})$$

Revenues

- We can derive the probability p_{gl}^{g} a consumer at location ℓ shops at store j from above using the standard logit formula.
- The model's predicted general merchandise revenue for store j is

$$R_j^g = \sum_{\{l | j \in \bar{B}_l^{Wal}\}} \gamma^g p_{gl}^g n_l$$

  where γ^g is spending per consumer and n_l are the number of consumers at location l
- Spending on food is modeled in a similar fashion.
- Parameters are estimated using MLE assuming differences between observed and predicted sales are due to measurement error.

Cannibalization Rates

- We can use our model to estimate the cannibalization rates
  1. Calculate what sales would be in a particular year for pre-existing stores if no new stores were opened in the year and if there were no new super-center conversions.
  2. Calculate predicted sales to pre-existing stores when the new store openings and super-center conversions for the particular year take place.
  3. The percentage difference in sales is equal to the cannibalization rate for that year.
- Constrained estimation of revenue function also uses reported cannibalization rates reported by Walmart.
- Cannibalization rates were approximately 1 percent per year.

CANNIBALIZATION RATES,
FROM ANNUAL REPORTS AND IN MODEL

Year	From Annual Reports	Demand Model (Unconstrained)	Demand Model (Constrained)
1998	n.a.	.62	.48
1999	n.a.	.87	.67
2000	n.a.	.55	.40
2001	1	.67	.53
2002	1	1.28	1.02
2003	1	1.38	1.10
2004	1	1.43	1.14
2005	1	1.27	1.00[a]

[a]Cannibalization rate is imposed to equal 1.00 in 2005.
Source: Estimates from the model and Wal-Mart Stores, Inc. (*Annual Report*, 2004, 2006).

Calibration

- Variable costs: labor costs are 7.5 percent of sales, land costs are 0.5 percent of sales, other costs are 17 percent of sales.
- $\mu = 0.24$ based on Wal-Mart reports.
- ρ_t is calibrate based on average yearly growth for Walmart.

Section 5 of the paper provides some of-the-envelop calculations to suggest that the estimation of operating profits are sensible and capture the trade-offs faced by Wal-Mart.

Remaining Parameters

- We need to identify and estimate the following parameters relating to density:

$$\theta = (\tau, \omega_1, \omega_2)$$

- τ: is the coefficient on distance between a store and its distribution center
- ω_1, ω_2: determine how fixed costs vary with population density in

$$c_j = \omega_1 \ln(Popden_j) + \omega_2 \ln(Popden_j)^2$$

A Deviation from the Optimal Expansion Path I

- Let a index deviations from the actual policy a^0 that Wal-Mart chose
- y_a is the the incremental operating profit from doing a^0 rather than a:

$$y_a \equiv \Pi(a^0) - \Pi(a)$$

where

$$\Pi(a) \equiv \sum_{t=1}^{\infty} (\rho_t \beta)^{t-1} \Big(\sum_{j \in B_t^{Wal}(a)} \pi_{jt}^g(a) + \sum_{j \in B_t^{Super}(a)} \pi_{jt}^f(a) \Big)$$

A Deviation from the Optimal Expansion Path II

- Similarly, define
  - $x_{1,a} \equiv \Delta D_a$: present value of difference in distribution-distance miles between the two policies
  - $x_{2,a} \equiv \Delta C_{1,a}$ present values of differences in $\ln(Popden_j)$
  - $x_{3,a} \equiv \Delta C_{2,a}$ present values of differences in $\ln(Popden_j)^2$
- Then the change in the present value of the costs is given by

$$C(a^0) - C(a) \; = \; x_a' \theta$$

Let there be a set of M linear inequalities, with each inequality indexed by a

Linear Moment Inequality Conditions

- Any deviation from the optimal expansion path must satisfy the inequality that

$$y_a \equiv \Pi(a^0) - \Pi(a) \ \geq \ C(a^0) - C(a) \ = \ x_a' \theta_0$$

where the true parameter under which the data were generated is given by θ^0 .

- Let there be a set of M linear inequalities, with each inequality indexed by a.

Linear moment inequality framework

- Let $\{z_{a,k}, k = 1, 2, ..., K\}$ be a set of K instruments for each a. With $z_{a,k} \geq 0$, so at the true parameter

$$z_{a,k} y_a \geq z_{a,k} x_a' \theta$$

  for all a and k.
- Measurement error:

$$\tilde{y}_a = y_a + \eta_a$$

  with $E[\eta_a | x_a, z_{ak}] = 0$.
- Taking expectations, we obtain a set of K moment inequalities that are satisfied at the true parameter θ^0, i.e.

$$m_k(\theta) \geq 0$$

  for $k \in 1, 2, ..., K$, where

$$m_k(\theta) = E[z_{a,k} \tilde{y}_a] - E[z_{a,k} x_a'] \theta$$

Linear moment inequality framework

- The identified set Θ^I is the subset of points satisfying the K linear constraints. Defining,

$$Q(\theta) = \sum_{k=1}^{K} (min\{0, m_k(\theta)\})^2$$

- The author shows that the sample analog of the identified set $\hat{\Theta}^I$ is a consistent estimate of the identified set Θ^I.

Deviations and Instruments

- Restricts attention to pairwise re-sequencing, For example, store number 1 actually opened in 1962 and number 2 opened in 1964. A pairwise re-sequencing would be to open store number 2 in 1962, store number 1 in 1964, and to leave everything else the same.
- Defines 12 deviation groups in one of the three broad classifications:
  - store density decreasing
  - store density increasing
  - population density changing (holds store density roughly constant by flipping stores opened in the same state)
- Taking means over inequalities within each group creates moment inequality for each group
- χ_a^k is an indicator variable $= 1$ if deviation a is in group k and $= 0$ otherwise $\Rightarrow$ a weighted version of these indicators serve as instruments $z_{a,k}$

Summary of Deviations

SUMMARY STATISTICS OF DEVIATIONS BY DEVIATION GROUP

Deviation Group	Brief Description of Group	Number of Deviations	Mean Values: $\Delta\tilde{\Pi}$ (millions of 2005 dollars)	ΔD (thousands of miles)	ΔC_1 (log *Popden*)	ΔC_2 (log *Popden*^{2})
	Store density decreasing					
1	$-.75 \leq \Delta D < 0$	64,920	-2.7	-0.4	-0.6	-3.0
2	$-1.50 \leq \Delta D < -.75$	61,898	-3.6	-1.1	-1.5	-9.0
3	$\Delta D < -1.50$	114,588	-4.7	-3.0	-3.4	-22.2
	Store density increasing					
4	$0 < \Delta D \leq .75$	158,208	3.0	0.3	-1.9	-17.2
5	$.75 < \Delta D \leq 1.50$	34,153	3.7	1.0	-3.6	-28.9
6	$1.50 < \Delta D$	16,180	5.9	2.1	-4.8	-37.7
	Population density changing					
7	Class 4 to Class 3	7,048	1.2	0.0	3.2	31.1
8	Class 3 to Class 2	10,435	3.7	0.0	3.4	25.7
9	Class 2 to Class 1	14,399	5.3	-0.1	3.5	19.3
10	Class 1 to Class 2	12,053	-2.4	0.0	-3.4	-19.3
11	Class 2 to Class 3	14,208	0.6	-0.1	-3.9	-29.4
12	Class 3 to Class 4	14,877	2.5	0.0	-4.6	-44.9
All	Weighted mean	522,967	-0.2	-0.6	-2.1	-15.6

Bounding the Key Parameter

- The main parameter of interest is τ which represents the cost savings in 1000s of dollars when a store is closer to its distribution center by one mile over the course of a year.
- The paper computes bounds of τ

  $$E[m_1] = E[\Delta\tilde{\Pi}_1] - \tau E[\Delta D_1] - \omega_1 E[\Delta C_1] - \omega_2 E[\Delta C_2] \geq 0$$

  through linear programs that impose the moment inequalities and the a-priori restrictions that $\omega_1 \geq 0, \omega_2 \leq 0$.

Estimates of τ

BASELINE ESTIMATED BOUNDS ON DISTRIBUTION COST τ[a]

	Specification 1 Basic Moments (12 Inequalities)		Specification 2 Basic and Level 1 (84 Inequalities)		Specification 3 Basic and Levels 1, 2 (336 Inequalities)	
	Lower	Upper	Lower	Upper	Lower	Upper
Point estimate	3.33	4.92	3.41	4.35	3.50	3.67

Conclusions

- One is that all economies of density are channeled through the benefits of stores being close to distribution centers.
- Benefits can potentially emerge through other channels, including *management* (it is easier for upper-level management to oversee a given number of stores when the stores are closer together) and *marketing* (satisfied Wal-Mart customers might tell their friends and relatives on the other side of town about Wal-Wal-Mart?this benefits Wal-Mart only if it has a store on the other side of town).
- No structural errors in the model.
- The analysis does not take explicit account of the location of competitors. There is no strategic interaction as in Jia (2008).