Imitation in Location Choice: Obstacle or Opportunity for Local Economic Development?

Nathan Berg*

Abstract: If the cost of gathering information about where profitable locations can be found affects firms' calculations of expected profits, then decentralized location choice by profit-maximizing firms is predicted to leave some neighborhoods in a state of urban blight with no formal commerce despite them having opportunities for profit. Planners often conclude that neighborhoods and regional economies persist in abandonment or decay because it is unprofitable for firms to locate there. Contrary to that intuition, this paper provides a new explanation for spatial lock-in based on privately optimal but socially inefficient information pooling, which works to the disadvantage of undeveloped geographic regions in attracting formal commerce. A simple model demonstrates that firms may rationally choose to overlook neighborhoods because they economize on the costs of gathering information. When firms condition their choices of location on earlier movers' choices, second-mover firms will sometimes find it optimal to imitate first-movers even though privately acquired information might suggest locating elsewhere. This mechanism based on decentralized decisions about how much new information to acquire implies that tax incentives used by planners to induce firms to move to enterprise zones targeted for economic development do little to influence decisions about where to locate.

Keywords: Urban Decay, Blight, Neighborhood Revitalization, Bounded Rationality, Cascades, Retail Desert, Imitation, Lock-In, Location, Enterprise Zone, Research Park, Informational Externality, Ecological Rationality
JEL Codes: D21, D61, L20, R14, R30

* *Nathan Berg:* University of Otago, PO Box 56, Dunedin 9054, New Zealand. Phone: (+64) 3-479-8648. Email: nathan.berg@otago.ac.nz.

1 Introduction

This paper presents a model of information acquisition and location choice among profit-maximizing firms. In contrast to theories based on the assumption of first-mover advantage, the model focuses on the informational advantage that second movers enjoy by conditioning on first movers' choices of location. Second movers' utilization of information revealed by first movers gives rise to the possibility of imitation as a profit-maximizing strategy for second movers. This rationalization of imitation in location choice based on informational spillovers in a model with sequential moves is distinct from spatial pooling in Hotelling linear city models. Second movers economizing on acquisition of private information when searching for profitable locations leads to socially inefficient spatial pooling, implying that profitable investment opportunities in neighborhoods with no first movers can remain underdeveloped. The root cause of spatial clustering in this simple model is informational pooling. Consequently, spatial inefficiency (in the context of the model) is simply the result of informational inefficiency, based on tension between private versus socially optimal intensities of information acquisition. The analysis shows that social inefficiency from missed locational opportunities—those locations that would have required second movers to bear greater costs of independent search and acquire more information about where profitable locations are—can be quantified as a function of the extent to which second movers substitute away from costly acquisition of private information into costless observation of first movers.

A primary motivation for modeling imitation in location choice is to investigate the possibility of behavioral barriers to local economic development in older, low-income neighborhoods within central cities with chronic vacancies in, or absence of, retail space. Berg (2014) reports empirical evidence of imitation in location choice using interview data collected from entrepreneurs. Brueckner and Rosenthal (2005) identify age of housing stock as a key predictor of future changes in neighborhood income, which naturally leads to comparisons of factors that influence new development in suburbs versus redevelopment within central cities. Observing low-income neighborhoods in central cities that are devoid of formal commerce, the standard neoclassical model suggests that, despite advantages such as the low cost of retail space and few competitors, firms evidently avoid these areas because they cannot profit by locating there. In contrast, the hypothesis considered here is that firms rationally apply an imitation heuristic for choosing locations that succeeds at maximizing profits in environments with abundant information, such as thriving big-box developments in the suburbs, while failing to exploit profitable locations in urban environments with little or no available information (and few, if any, observable first movers) concerning revenues and costs. In such low-information environments with limited retail activity, stigmatizing perceptions may result in lock-in, because lack of new entrants into these neighborhoods blocks the revelation of information about profit opportunities.

The model reveals conditions under which imitation in location choice is consistent with individual profit maximization. In so doing, the model provides a benchmark for addressing the normative question of how imitation affects aggregate efficiency. Incentives that rationalize imitation from the point of view of individual firms can, according to the model, lead to socially inefficient neglect of profitable locations—for example, when firms do not consider moving into a neighborhood simply because no other firms are observed there, and not because expected profits were actually estimated and judged to be unattractive.

For parameterizations with low costs of private information, the model's first movers acquire large quantities of private information, and imitation by second movers is consistent with social efficiency (i.e., maximization of aggregate profit by a centrally coordinated program designed to efficiently exploit the positive informational externality flowing from first to second movers). In this case, the first mover is so well informed about where to find good locations that second movers learn almost all they need to know about where good locations are—and, consequently, centralized and decentralized location choice regimes differ very little. As information becomes more expensive, however, imitation becomes increasingly inconsistent with aggregate efficiency, because first movers acquire only small quantities of private information and the missed aggregate benefits caused by second movers that imitate rather than aggregating additional private information grow larger. Social inefficiency turns out to be non-monotonic in the cost of information, however. When information or search costs are extremely large, decentralized and coordinated choice of locations both demand very little information, and the gap in aggregate profits between decentralized and coordinated location choice shrinks. Inefficiency approaches zero at the other extreme of the cost-of-information spectrum as the cost of private information approaches zero. Thus, efficiency losses are largest in the intermediate range of the cost of private information.

Interest in theoretical mechanisms that lead to socially inefficient spatial lock-in among retailers draws, in part, on recent evidence that even sophisticated retailers with numerous store locations, such as Starbucks and Home Depot, have discovered that their own revenue prediction models led them to mistakenly overlook profitable locations in low-income neighborhoods (Weissbourd, 1999; Helling and Sawicki, 2003; Sabety and Carlson, 2003). For example, Vice President of Starbuck's Store Development Cydnie Horwat writes: "Our Urban Coffee Opportunities joint venture has essentially shown that Starbucks can penetrate demographically diverse neighborhoods in underserved communities, such as our store in Harlem, which is not something that we had previously looked at" (Francica, 2000).

How could Starbucks have persistently overlooked profitable locations, and why did discovering those missed opportunities require a joint initiative under pressure from non-profits and activists promoting new commercial ventures in poor neighborhoods? Are neighborhoods in central cities that retailers typically avoid really less profitable? Or do interdependencies among firms' location decisions lead to inefficient lock-in at a status quo biased against discovery of commercial opportunities in low-income with large concentrations of ethnic minorities simply because other firms have decided against locating there in the past?

The model presented below suggests it is unsurprising to find that imitation heuristics are widely used by business decision makers when choosing locations because, in many environments, imitation heuristics are consistent with individual profit maximization after factoring in search and information costs. The model also demonstrates and provides a means of quantifying the social cost of imitation in location choice. The behavioral mechanism of imitation functions well in some environments but can lead to socially inefficient intensities of spatial concentration among retailers. This theoretical finding suggests one plausible explanation for why neighborhoods that should be capable of sustaining profitable retail activity—and would do so, if firms conducted independent calculations of expected profit—sometimes wind up in a state of chronic underdevelopment, failing to attract formal commercial activity over a sustained period of time.

One mechanism through which information diffusion might get stuck near zero concerns perceptions about crime in low-income neighborhoods. It is unclear the extent to which models of crime documented as a factor in residential location (Helsley and Strange, 1999; Verdier, T., and Zenou, 2004; Helsley and Strange, 2005; Berg, Hoffrage and Abramczuk, 2010) extend to the case of retail location choice. Practitioners seeking to facilitate greater numbers of new business starts in low-income neighborhoods suggest that perceived risks and costs of crime indeed play a large role in conditioning firms' decisions avoiding stigmatized neighborhoods (Bray, 2007; Weissbourd, 1999). Similarly, interview data with business decision makers responsible for location choice (Berg, 2014) confirm that many firms cite crime as a reason for avoiding particular neighborhoods although they rarely (if ever) conduct quantitative benefit-cost assessments to justify such deletions from their consideration sets. Instead, the decision processes underlying many firms' choices of location rely on imitation heuristics and threshold rules (i.e., satisficing) used to quickly narrow down the consideration set to a handful of candidates, in line with the ideas of Simon (1954, 1955), Cyert and March (1963), March (1988) and Noble, Todd and Tuci, (2001).

Concerning the normative focus of this paper, it is useful to recall that spatial agglomeration, or clustering, in the classic Hotelling (1929) model is socially wasteful (although individually payoff-maximizing) because transportation costs are not minimized. Hotelling, and later Boulding (1996), generalized the idea of socially wasteful agglomerations to a broad range of social settings. This negative assessment was later tempered by arguments emphasizing benefits from spatial agglomeration, which helps consumers by economizing on shopping costs in terms of shopping time, transportation cost (Eaton and Lipsey, 1976, 1979) and reduction of uncertainty (Wolinsky,1983; Dudey, 1990). Following numerous papers on efficiency gains from agglomeration, however, negative assessments based on new mechanisms also appeared (e.g., see Dudey, 1993, on welfare-decreasing agglomerations). Theoretical and empirical work often emphasizes the role of physical distance in the production function—indivisibility in production (Kanemoto, 1990), labor market pooling (Rosenthal and Strange, 2001), and complementarity between workers and firms (Andersson, Burgess and Lane, 2007)—when characterizing the efficiency of spatial agglomerations. Rather than trying to harmonize conflicting normative theories (e.g., as described by Fischer and Harrington, 1996), this paper attempts to represent these mixed normative interpretations in the spatial agglomeration literature with a simple model in which: (i) spatial imitation can be rationalized as individually profit maximizing, and (ii) the aggregate inefficiency of spatial patterns (generated by second movers who economize by using information spillovers to choose locations by imitation) can be expressed as a non-monotonic function of the cost of information.[1]

The plan of this paper is as follows. Section 2 presents the model and main theoretical results. Section 3 discusses these results in the context of three research literatures linking imitation, spatial agglomeration and local economic development. Section 4 returns to the problem of underutilized resources in urban areas with possible interpretations of the model when applied to the case of urban ghettos devoid of retail or other visible forms of commerce.

[1]Gigerenzer et al (1999) and Gigerenzer and Selten (2002) advocate a normative approach that they refer to as ecological rationality, analyzing when decision procedures are well matched, or badly matched, to the decision environments in which they are used. This matching concept underlying ecological rationality contrasts with standard axiomatic notions of rationality that require consistency across all decision contexts. Townroe (1991), for example, argues in favor of expanding normative analysis of location choice to include multiple or pluralistic notions of rationality. Context-dependent normative analysis does not imply relativity, as there remain many theoretically systematic and empirically motivated reasons (other than violations of consistency axioms) for policy makers to be concerned about behavioral underpinnings of spatial agglomerations. Berry (1961), for example, argues that steepness of the distribution curve describing city sizes is inversely related to economic development and, therefore, that policy makers interested in fostering local economic development should analyze behavioral mechanisms that lead to spatial agglomeration as a primary issue in urban planning. Bergsman, Greenston and Healy (1972) provide an early and important empirical account of agglomeration forces. Muñiz and Galindo (2005) present evidence on suburban agglomerations and environmental impacts. Anas and Rhee (2007) demonstrate the sensitivity of normative evaluations of policies that concern spatial agglomerations to apparently innocuous assumptions such as exogenous agricultural land rents in areas surrounding cities. Similarly, Turner (2007) analyzes free-rider microstructures that lead to a large divergence between equilibrium and socially efficient spatial distributions.

2 The Model

The model considers firms that have two choice variables: how much private information to acquire about locations and choice of location. Following extensive theoretical (Prescott and Visscher, 1977; Kogut, 1983) and empirical literatures (Chang, 1995; Chang and Rosenzweig 2001; Chung, 2001) on sequential entry and exit, the model assumes that each firm makes a joint decision of information acquisition and location choice at a single point in time as part of a longer sequence of joint decisions by other firms.

The analysis below investigates the effect of a firm's position in this temporal sequence on information acquisition. The model is stylized to focus on the extent to which firms condition their choices of location on previous movers' locations instead of collecting independent information on their own. Therefore, the analysis assumes that firms' objective functions differ only in the sets of information (which consist of observed locations chosen by earlier movers) used as conditioning information when calculating expected profit. Heterogeneous expected profit functions across firms (and, consequently, heterogeneous decisions about information acquisition and location) arise because of each firm's different position in the exogenously given sequence of moves, which implies that each firm has a different information set given by the location decisions of all other firms earlier in the sequence.

To fix ideas, the simplest sequence consists of only two firms. The first mover is referred to as Firm 1. The second mover is referred to as Firm 2. Firm 2 moves after observing Firm 1's choice of location. In the first period, Firm 1 chooses a quantity of information and location to maximize its expected profit. In period 2, Firm 2 chooses a quantity of information and location to maximize expected profit conditional on Firm 1's location.

Locations are indexed on the unbounded real line. Because the focus is information acquisition rather than strategic considerations (or other problems such as multiple equilibria, Knightian uncertainty or a dynamical system analysis), a shortcut is taken by assuming the existence of a unique profit-maximizing location $a \in \Re$, referred to as the *ideal location.*The reason for assuming that there is one ideal location that both firms would choose if this unique profit-maximizing location, a, were known is to grant that spatial pooling at a single location may in fact be ideal. This methodological choice makes it harder to demonstrate socially inefficient imitation of location choice. The goal is to avoid "cooking up" a structure where spatial pooling is suboptimal and then trivially showing that social inefficiency results from firms choosing the same location. Instead, the assumed existence of a grants the existence of a universally best location for any firm, regardless of other firms' decisions. Given the existence of this social optimum (used as a benchmark for subsequent comparisons of social efficiency), the analysis below focuses on rationalizing the informational and spatial lock-in that occurs when firms use an imitation heuristic to choose locations (as opposed to generating independent information correlated with a). This rationalization is intended to demonstrate that firms imitate because it works well from their point of view. The model will show that imitation can increase the second mover's expected profit even when those first movers who are being imitated, almost surely, have not succeeded in discovering a.

Information acquisition is one of two key decision variables that each firm must choose, because the ideal location a is unknown to both firms. Both firms choose quantities of information (described in the next paragraph), denoted θ_1 and θ_2, respectively, that describe the information content (i.e., correlation with a) of the private signals that each firm pays to acquire, denoted as random variables representing each firm's independently obtained private signal, x_1 and x_2. Firm 1 pays to acquire its private signal x_1 (whose correlation with a is determined by its quantity of information decision θ_1) and chooses its location, denoted y_1. Next, Firm 2 pays to acquire its private signal x_2 (which could be more strongly, or more weakly, correlated with a than x_1, depending on how much Firm 2 chooses to pay for its private signal, i.e., determined by the relative sizes of θ_1 and θ_2). The important difference between the firms' objective functions is that, when Firm 2 chooses its location denoted y_2, it conditions its expectation of a on both its private signal (x_2) and the observed location of Firm 1 (y_1).

The choice variables measuring quantities of private information that each firm decides to acquire are denoted θ_1 and θ_2, $0 \leq \theta_i \leq 1$, $i = 1, 2$. The *quantity of information* θ_i represents the theoretical R^2 in a univariate regression of a on the privately acquired signal x_i. Larger θ_i means that Firm i chooses more private information or, equivalently, higher correlation with a, or lower conditional variance of a given x_i.

Privately acquired signals come from a variety of sources, including public data sets and private vendors, both of which incur time, processing and sometimes explicit financial costs. The model represents these costs of acquiring private information with a continuously differentiable and weakly increasing cost function $C(\theta)$, such that $C(0) = 0$ and $C'(\theta) \geq 0$. From Firm 2's point of view, in addition to any private information it acquires for itself, it also has available the observed location choice of Firm 1. Under the assumption that this information is free for Firm 2 to observe, Firm 2's use of the information in y_1 does not affect Firm 2's cost of private information (which depends only on the quantity of private information it chooses when acquiring x_2, $C(\theta_2)$).

If either firm knew where the best location was (i.e., knew a), then profit would be given by the exogenous parameter π_0, interpreted as maximized profit in the ideal case of full knowledge with zero information costs. Given uncertainty about a, however, firms incur costs that reduce profit from π_0 by two mechanisms in the assumed profit function introduced below. First, each firm's location choice generates costs associated with deviating from the ideal location a, interpreted as reduced sales revenue, extra transportation costs or other location-specific costs. Second, each firm's choice of how much private information to acquire generates costs represented by $C(\theta)$. With quadratic costs of deviating from a, the profit function takes the form:

$$\pi_0 - (y_i - a)^2 - C(\theta_i),\ i = 1, 2. \tag{1}$$

Because a is uncertain, each firm's *ex ante* objective function is computed as a conditional expectation (conditioning on different information sets, with the distributions of private signals parameterized by quantity of information choice variables, θ_1 and θ_2):

$$\begin{aligned}
\pi_1(y_1, \theta_1) &= \pi_0 - \mathrm{E}[(y_1 - a)^2 | x_1; \theta_1] - C(\theta_1), & (2)\\
\pi_2(y_2, \theta_2) &= \pi_0 - \mathrm{E}[(y_2 - a)^2 | y_1(\theta_1), x_2; \theta_2] - C(\theta_2). & (3)
\end{aligned}$$

As stated earlier, the *ex ante* profit functions of Firm 1 and Firm 2, expressed as conditional expectations in (2) and (3), differ only in the information upon which expectations are conditioned. The notation makes clear that Firm 1's expectation of expressions involving a is conditioned by its private information x_1, which depends on its choice of θ_1. Firm 2's expectation of expressions involving a is conditioned by Firm 1's location $y_1(\theta_1)$ and Firm 2's privately acquired signal x_2. Firm 2's expectations depend on its choice of θ_2. The notation in equation (3) expresses y_1 as a function of θ_1 to make the dependence of Firm 2's information acquisition on Firm 1's choice of information explicit.

Expected deviations from a, which appear in each firm's expected profit function, are decomposed as follows:

$$\begin{aligned} \mathrm{E}[(y_1 - a)^2 | x_1; \theta_1] &= (y_1 - \mathrm{E}[a|x_1;\theta_1])^2 + \mathrm{var}(a|x_1;\theta_1), \quad (4) \\ \mathrm{E}[(y_2 - a)^2 | y_1(\theta_1), x_2; \theta_2] &= (y_2 - \mathrm{E}[a|y_1(\theta_1), x_2;\theta_2])^2 + \mathrm{var}(a|y_1(\theta_1), x_1;\theta_2). \quad (5) \end{aligned}$$

Because the first terms on the right hand-side of (4) and (5) have unique minima at zero, and because y_i appears nowhere else in Firm i's objective function, the optimal location choice rules are given by:

$$y_1^* = \mathrm{E}[a|x_1;\theta_1] \quad \text{and } y_2^* = \mathrm{E}[a|y_1(\theta_1), x_2;\theta_2]. \quad (6)$$

One observation that directly follows from (6) based on the definition of the conditional expectation operator is that, whenever Firm 2 acquires no private information ($\theta_2 = 0$), it chooses to imitate Firm 1's location only to the extent that Firm 1's private information is revealed by its observed location choice, which depends on the linearity of Firm 1's location choice rule as a function of its private information. If y_1^* is linear in x_1, then (because linearity perfectly reveals the correlational information in Firm 1's private signal) $y_2^* \to y_1^*$ as $\theta_2 \to 0$. In other words, if Firm 2 receives an undistorted copy (i.e., a linear transformation) of Firm 1's private signal when it observes where Firm 1 chooses to locate, and if Firm 2 acquires no private information of its own, then Firm 2 must have the same expectation of a and consequently choose the same location as Firm 1.

After substituting (4) into (2), the first-order condition for θ_1 is:

$$2(y_1 - \mathrm{E}[a|x_1;\theta_1])\frac{\partial \mathrm{E}[a|x_1;\theta_1]}{\partial \theta_1} - \frac{\partial \mathrm{var}(a|x_1;\theta_1)}{\partial \theta_1} - \frac{\partial C(\theta_1)}{\partial \theta_1} = 0. \quad (7)$$

Because the global solution for y_1^* in (6) makes the first term in parentheses on the left-hand side of (7) uniformly zero, the first-order condition in (7) simplifies to $-\frac{\partial \mathrm{var}(a|x_1;\theta_1)}{\partial \theta_1} = \frac{\partial C(\theta_1)}{\partial \theta_1}$. The first-order condition requires that Firm 1 choose θ_1 such that the marginal reduction in the conditional variance of a equals the marginal cost of information. A solution to this first-order condition for θ_1 may not exist, however. And if it does exist, it may not yield the global maximum, which can occur instead at boundary values (i.e., corner solutions). The boundary values, $\theta_1 = 0$ and $\theta_1 = 1$, must be checked. The choice $\theta_1 = 0$ maximizes expected profit when information is too expensive to justify its acquisition at any level, in which case Firm 1 locates at the unconditional mean, $y_1 = \mu_a$, and achieves expected profit $\pi_0 - \sigma_a^2$. The choice $\theta_1 = 1$ represents the case where Firm 1 acquires a maximally precise signal revealing the exact value of a, which implies that $\text{var}(a|x_1;\theta_1)|_{\theta_1=1} = 0$ and profit $\pi_0 - C(1)$ (with certainty and not in expectation).

Given the real-world policy problems associated with the hypothesis of imitation causing inefficient spatial agglomerations that fail to find and utilize profitable opportunities across different regions of a city, the analysis here focuses on the case in which Firm 1 acquires private information but Firm 2 does not:

$$\theta_1 > 0 \text{ and } \theta_2 = 0, \tag{8}$$

referred to as *absolute imitation.* Next, conditions are identified under which absolute imitation can be rationalized as consistent with expected-profit maximization. It is assumed that the global maximizer θ_1^* lies on the strict interior of the unit interval: that is, $\pi_1(\text{E}[a|x_1;\theta_1^*], \theta_1^*) > \max\{\pi_0 - \sigma_a^2, \pi_0 - C(1)\}$.[2] Conditions are also sought under which Firm 2 acquires private information, but strictly less information than Firm 1:

$$0 < \theta_2^* < \theta_1^*, \tag{9}$$

referred to as partial imitation, because y_2^* and y_1^* are closer on average than they would be if location choices were based solely on private signals with independent

[2] A sufficient but not necessary condition for existence of an interior solution for θ_1 is that the conditional variance of a given x_1 is weakly convex in θ_1, which holds, for example, in case a and x_1 are jointly normal, as shown in later sections.

noise terms.

Turning to Firm 2's optimal information acquisition rule, the first-order condition for θ_2 is:

$$-\frac{\partial \text{var}(a|y_1(\theta_1), x_2; \theta_2)}{\partial \theta_2} = \frac{\partial C(\theta_2)}{\partial \theta_2}, \tag{10}$$

which makes clear the dependence of Firm 2's choice of θ_2 on θ_1. Again, this first-order condition may not have a solution, and any solution may be dominated (in expected profit) by choices at the boundaries. In cases where $-\frac{\partial \text{var}(a|y_1(\theta_1), x_2; \theta_2)}{\partial \theta_2} < \frac{\partial C(\theta_2)}{\partial \theta_2}$ for all θ_2, Firm 2's marginal benefit of private information is never greater than its marginal cost. The following result describes conditions under which Firm 2 rationally chooses to acquire no private information.

Result 1 (Absolute Imitation): If (i) $C(\theta)$ is convex, (ii) $\text{var}(a|y_1(\theta_1), x_2; \theta_2)$ is convex in θ_2 (i.e., Firm 2's marginal benefit of private information acquisition is decreasing in θ_2), and (iii) the following inequality holds:

$$-\frac{\partial \text{var}(a|y_1(\theta_1), x_2; \theta_2)}{\partial \theta_2}|_{\theta_2=0} < \frac{\partial C(0)}{\partial \theta} < -\frac{\partial \text{var}(a|x_1; \theta_1)}{\partial \theta_1}|_{\theta_1=0}, \tag{11}$$

then Firm 2 absolutely imitates Firm 1.

Absolute imitation means that Firm 2 acquires no private information of its own (i.e., $\theta_2^* = 0$), while Firm 1 acquires a strictly positive quantity of information (i.e., $\theta_1^* > 0$). If Firm 1's location is linear in its private signal, then the conditions in Result 1 also imply that Firm 2 chooses the same location as Firm 1: $y_2^* = y_1^*$.

Condition (11) relies on the fact that, if the marginal benefit of private information is less than its marginal cost (at the initial position of zero information and everywhere else, i.e., for all $\theta_2 \in [0, 1]$), then there is no incentive for Firm 2 to acquire information. Firm 2's marginal benefit is decreasing in private information acquisition (by convexity of Firm 2's conditional variance), and marginal cost is increasing (by convexity of the cost function). Therefore, the first inequality rules out that Firm

2 would ever find it worthwhile to acquire private information. The second inequality ensures that Firm 1 acquires a positive quantity of private information.[3]

2.1 Joint normality

To express the interdependence of the two firms' decisions about quantities of private information (using tractable functional forms), the case of jointly normal private signals with independent (i.e., firm-specific) errors in the production of private information is considered first:

$$a \sim \mathrm{N}(\mu_a, \sigma_a^2), \quad x_1 = a + \epsilon_1, \quad \text{and} \quad x_2 = a + \epsilon_2, \tag{12}$$

where ϵ_i is normal, with mean $-\mu_a$ (so that, without loss of generality, $\mathrm{E}[x_i] = 0$), and independent from a, for $i = 1, 2$. Thus, each firm's acquisition of information can be expressed as:

$$\theta_i \equiv [\mathrm{corr}(x_i, a)]^2 = (\sigma_a^2)^2/(\sigma_a^2\sigma_i^2) = \sigma_a^2/\sigma_i^2, \tag{13}$$

where $\sigma_i^2 \equiv \mathrm{var}(x_i)$, $i = 1, 2$, and independence of errors implies $\mathrm{corr}(\epsilon_1, \epsilon_2) = 0$.

Joint normality provides convenient formulas for conditional expectations. Recalling that x_1 has (by definition) an unconditional mean of zero, then Firm 1's conditional expectation of a (and by equation (6), its expected-profit-maximizing location) is:

$$y_1^* = \mu_a + [\mathrm{cov}(x_1, a)/\sigma_1^2]x_1 = \mu_a + \theta_1 x_1. \tag{14}$$

Conditional variance of a given Firm 1's observed signal is given by the fomula:

$$\mathrm{var}[a|x_1] = \sigma_a^2 - [\mathrm{cov}(x_1, a)]^2/\sigma_1^2 = \sigma_a^2(1 - \theta_1). \tag{15}$$

The condition under which Firm 1 acquires a positive quantity of information [the second inequality in (11) requiring that the marginal cost of the first unit of

[3]For more on the value of information and its interactions with risk aversion, not considered further here, see Willinger (1989), Hilton (1981), Eeckhoudt, Godfroid and Gollier (2001), and Berg and Hoffrage (2008).

information is less than its marginal benefit] simplifies to $C'(0) < \sigma_a^2$. If this condition is satisfied, then Firm 1's optimal quantity of private information is the interior solution θ_1^* that solves the first-order condition:

$$\sigma_a^2 = C'(\theta_1). \tag{16}$$

After substituting $\sigma_1^2 = \sigma_a^2/\theta_1$, $\sigma_2^2 = \sigma_a^2/\theta_2$, and $\mathrm{var}(y_1) = \theta_1^2(\sigma_a^2/\theta_1) = \theta_1\sigma_a^2$, then Firm 2's conditional expectations, $\mathrm{E}[a|y_1, x_2]$ and $\mathrm{var}(a|y_1, x_2)$, can be expressed in terms of θ_1 and θ_2:

$$\begin{aligned}
\mathrm{E}[a|y_1(\theta_1), x_2; \theta_2] &= \mu_a + [\mathrm{cov}(y_1, a)\ \mathrm{cov}(x_2, a)] \begin{bmatrix} \mathrm{var}(y_1) & \mathrm{cov}(y_1, x_2) \\ \mathrm{cov}(y_1, x_2) & \mathrm{var}(x_2) \end{bmatrix}^{-1} \begin{bmatrix} y_1(\theta_1) - \mu_a \\ x_2 \end{bmatrix} \\
&= \mu_a + [\theta_1\sigma_a^2 \quad \sigma_a^2] \begin{bmatrix} \theta_1\sigma_a^2 & \theta_1\sigma_a^2 \\ \theta_1\sigma_a^2 & \sigma_a^2/\theta_2 \end{bmatrix}^{-1} \begin{bmatrix} \theta_1 x_1 \\ x_2 \end{bmatrix} \qquad (17) \\
&= \mu_a + \frac{\theta_1(1-\theta_2)}{1-\theta_1\theta_2} x_1 + \frac{\theta_2(1-\theta_1)}{1-\theta_1\theta_2} x_2, \qquad (18)
\end{aligned}$$

and:

$$\begin{aligned}
\mathrm{var}(a|y_1(\theta_1), x_2; \theta_2) &= \sigma_a^2 - [\theta_1\sigma_a^2 \quad \sigma_a^2] \begin{bmatrix} \theta_1\sigma_a^2 & \theta_1\sigma_a^2 \\ \theta_1\sigma_a^2 & \sigma_a^2/\theta_2 \end{bmatrix}^{-1} \begin{bmatrix} \theta_1\sigma_a^2 \\ \sigma_a^2 \end{bmatrix} \qquad (19) \\
&= \sigma_a^2[1 - (\theta_1 + \theta_2 - 2\theta_1\theta_2)/(1 - \theta_1\theta_2)]. \qquad (20)
\end{aligned}$$

Equation (18) implies that the more information Firm 1 acquires, the less weight Firm 2 places on its own private signal (i.e., $\frac{\partial}{\partial\theta_1}[\theta_2(1-\theta_1)/(1-\theta_1\theta_2)] = -\theta_2(1-\theta_2)/(1-\theta_1\theta_2)^2 \leq 0$). As long as $\theta_1 > \theta_2$, then equation (18) also shows that Firm 2 will rationally place more weight on Firm 1's information than its own; and if $\theta_2 = 0$, Firm 2 chooses to locate precisely where Firm 1 chose to locate: $y_2^* = y_1^* = \mu_a + \theta_1 x_1$.

It is worthwhile confirming that the conditions in Result 1, which describe where absolute imitation occurs, are satisfied. The following expression measures Firm 2's marginal benefit from its own (possibly zero) private information:

$$-\frac{\partial \mathrm{var}(a|y_1(\theta_1), x_2; \theta_2)}{\partial \theta_2} = \sigma_a^2(1-\theta_1)^2/(1-\theta_1\theta_2)^2. \tag{21}$$

Taking the second derivative with respect to θ_2 reveals an obvious negative sign (on the relevant ranges of the unit interval on which θ_i, $i = 1, 2$, is defined), which demonstrates the convexity of conditional variance [i.e., the second derivative of $\mathrm{var}(a|y_1(\theta_1), x_2; \theta_2)$ without the negative sign is positive], as required in Result 1. To see if the other part of Result 1's absolute imitation condition holds, a specification of the cost function is required. If both firms choose interior quantities of information, then they will equate the marginal benefit of private information with its marginal cost. For any strictly increasing cost function, Firm 2 will acquire less private information than Firm 1 if and only if Firm 2's marginal benefit is less than Firm 1's. This inequality clearly holds in the case of joint normality:

$$-\frac{\partial \mathrm{var}(a|y_1(\theta_1), x_2; \theta_2)}{\partial \theta_2} = \sigma_a^2[(1-\theta_1)/(1-\theta_1\theta_2)]^2 \leq \sigma_a^2 = -\frac{\partial \mathrm{var}(a|x_1; \theta_1)}{\partial \theta_1}. \tag{22}$$

Result 2 (Firm 2 demands less private information than Firm 1): If $C(\theta)$ is strictly increasing and a, x_1 and x_2 are jointly normal, then Firm 2 demands less private information than Firm 1: $\theta_2^* \leq \theta_1^*$.

Result 2 follows from the fact that Firm 1's marginal benefit of private information is uniformly greater than Firm 2's as demonstrated in (22). A functional form describing a parametric family of cost functions is introduced next to demonstrate the generic existence and plausibility of joint information-and-cost structures in which imitation by second movers is rationalizable.

2.2 Example with exponential cost of information

Suppose the cost function takes the following (inverse) exponential form:

$$C(\theta) = -c \log(1-\theta), \quad c > 0. \tag{23}$$

The most important feature of this cost function is that the first unit of information has a strictly positive marginal cost c and approaches infinity as θ approaches 1. Solving (16) leads to Firm 1's demand function for private information: $\theta_1^* = 1 - c/\sigma_a^2$ for $0 \leq c \leq \sigma_a^2$, and 0 otherwise. Referring back to Result 1, it is straightforward to verify that the condition for absolute imitation holds on the range $c < \sigma_a^2$ (where Firm 1 demands a strictly positive quantity of private information):

$$\begin{aligned} -\frac{\partial \text{var}(a|y_1(\theta_1), x_2; \theta_2)}{\partial \theta_2}|_{\theta_2=0} &= \sigma_a^2(1-\theta_1^*)^2 = (c/\sigma_a^2)c \\ &< c = \frac{\partial C(0)}{\partial \theta} \leq \sigma_a^2 = -\frac{\partial \text{var}(a|x_1; \theta_1)}{\partial \theta_1}|_{\theta_1=0}. \end{aligned} \tag{24}$$

With the cost function (23) in place, Firm 1 acquires a positive quantity of private information (provided that the marginal cost of the first unit, c, is not prohibitively high); Firm 2 absolutely imitates Firm 1 (by not acquiring any private information of its own); and Firm 2 locates precisely at Firm 1's location, $y_2^* = y_1^*$, illustrating the case of absolute imitation described in Result 1.

Without the benefit of observing Firm 1's location, Firm 2 would have acquired the same positive quantity of private information that Firm 1 did. The observability of Firm 1's location provides a free source of information, however, that reduces Firm 2's marginal benefit from costly production of private information (so much so, that Firm 2's marginal benefit of private information lies uniformly below its marginal cost). Firm 2 never acquires private information after observing Firm 1's location. Firm 2 therefore rationally chooses to locate wherever Firm 1 decided to locate.

2.3 Aggregate efficiency and absolute imitation

Firm 1 cannot capture the positive informational externality that its location decision, which is easy to observe, provides to Firm 2. To measure aggregate inefficiency resulting from this informational externality, it is useful to compare aggregate profits between two cases. In the decentralized case, both firms make information and location choices on their own. In contrast, in the centralized or coordinated case, there is a single owner of Firms 1 and 2, which are now interpreted as subsidiaries of a parent firm, or are otherwise guided by a central planner when making location choices. In the centralized or coordinated case, Firms 1 and 2 simultaneously choose θ_1, θ_2, y_1 and y_2 to maximize the aggregate profit function $\pi_1(y_1, \theta_1) + \pi_2(y_2, \theta_2)$. Coordinated maximization of aggregate profits requires that y_1 and y_2 are chosen to equal each firm's respective conditional expectation of a and that the information acquisition variables θ_1 and θ_2 are chosen simultaneously to maximize:

$$2\pi_0 - \sigma_a^2(1-\theta_1) - \sigma_a^2[1-(\theta_1+\theta_2-2\theta_1\theta_2)/(1-\theta_1\theta_2)] + c\log(1-\theta_1) + c\log(1-\theta_2). \quad (25)$$

Interpreting the coordinated planner as a sophisticated retailer (recalling the discussion of Starbucks and Home Depot in the introduction), the model reveals that the puzzle of a sophisticated retailer engaging in apparently unsophisticated imitation can also be rationalized. The coordinated planner's first-order condition for θ_2 is the same as Firm 2's individual first-order condition. Therefore, the planner chooses $\theta_2 = 0$ and $y_2 = y_1$ (just as Firm 2 would choose in the decentralized case). The planner, however, chooses a substantially larger quantity of information for Firm 1:

$$\theta_1^{*Planner} = 1 - \frac{1}{2}c/\sigma_a^2 = \frac{1}{2} + \frac{1}{2}\theta_1^*. \quad (26)$$

The expression above associates the planner's optimal value of θ_1 to Firm 1's individually rationalizable choice in the decentralized regime, showing that the coordinated planner always chooses a larger value for the first mover.

The intuition is straightforward. Private information acquired by the first mover improves the profits for all subsequent movers by shrinking deviations from the ideal location. The coordinated planner therefore concentrates all expenditures on private information production into the first mover's private information and location choice, letting all subsequent movers share that information and imitate.

The increased quantity of information that the coordinated planner chooses relative to the smaller quantities produced in the decentralized regime raises aggregate profits above the level achieved in the decentralized case. The difference between aggregate profits in the coordinated versus decentralized cases is a straightforward calculation, yielding the following increase in aggregate profit under coordinated information and location choice: $c(1+\log(1/2))$. To gauge how large a change in aggregate profits this would be in percentage terms, one refers back to aggregate profit in the decentralized case: $2\pi_0 - 2c + c\log(c/\sigma_a^2)$. The percentage change depends on the magnitude of c relative to π_0, which can be adjusted (within a large and dense subset of the admissible parameter space) to achieve arbitrarily large percentage changes, provided $c > 0$. These formulas show that the level of change in aggregate profits, as a measure of inefficiency in the decentralized case—based on the thought experiment of moving from decentralized to coordinated location choice—is proportional to the cost-of-information parameter c. Therefore, inefficiency is most severe when information acquisition is expensive and least severe when information is cheap. This claim depends critically on specification of $C(\theta)$, however. The next subsection shows that inefficiency in the decentralized case turns out to be non-monotonic in c when the cost function is quadratic.

2.4 Quadratic cost of information

While the case of absolute imitation starkly captures the real-world phenomenon of imitation in location choice (i.e., the complete absence of any cost-benefit analysis by second movers of unoccupied locations), the intermediate case is interesting as well: where Firm 2 conditions on Firm 1's location but also acquires private information. The remaining analysis relies on the following quadratic specification of the cost-of-information function:

$$C(\theta) = c\theta^2/2. \tag{27}$$

An important feature of this cost function is that the first unit of information has zero marginal cost, implying that both firms always acquire positive quantities of private information. Solving (16) for the decentralized case leads to:

$$\theta_1^* = \sigma_a^2/c, \text{ for } \sigma_a^2 \leq c, \text{ and 1 otherwise,} \tag{28}$$

or $\theta_1^* = \min\{\sigma_a^2/c, 1\}$.

Firm 2's objective function with quadratic costs of private information can be written as:

$$= \quad \pi_0 - (y_2 - \mathrm{E}[a|y_1(\theta_1), x_2; \theta_2])^2 - \sigma_a^2[1 - (\theta_1 + \theta_2 - 2\theta_1\theta_2)/(1 - \theta_1\theta_2)] - c\theta_2^2/2.$$

The first-order condition for θ_2 is:

$$\sigma_a^2(1 - \theta_1)^2/(1 - \theta_1\theta_2)^2 - c\theta_2 = 0. \tag{29}$$

Assuming $\sigma_a^2 \leq c$, the interior maximizer is solved by dividing (29) through by c and substituting $\theta_1 = \sigma_a^2/c$, which gives rise to a cubic in θ_2 that turns out to have a unique solution on the unit interval, as follows. After making the substitutions just described, it is straightforward to re-express (29) using the characteristic equation $h(\theta_2)$:

$$h(\theta_2) \equiv \theta_1^2\theta_2^3 - 2\theta_1\theta_2^2 + \theta_2 - \theta_1(1 - \theta_1)^2 = 0. \tag{30}$$

Because $h(0) = -\theta_1(1-\theta_1)^2 \leq 0$, and $h(1) = (1-\theta_1)^3 \geq 0$, there exists at least one solution on the interval $0 \leq \theta_2 \leq 1$. To rule out the possibility of multiple solutions on the closed unit interval, non-monotonicities of $h(\theta_2)$ are examined. If non-monotonicities exist, then they must occur at zeros of the following equation:

$$\frac{\partial h(\theta_2)}{\partial \theta_2} = 3\theta_1^2\theta_2^2 - 4\theta_1\theta_2 + 1 = (1-\theta_1\theta_2)(1-3\theta_1\theta_2) = 0. \quad (31)$$

There are two points at which the sign of the $h(\cdot)$ curve's slope can change: $\theta_2 = 1/(3\theta_1)$ and $\theta_2 = 1/\theta_1$. The second of these is necessarily to the right of $\theta_2 = 1$, implying that (30) has exactly one solution on the unit interval.

Result 3 (Partial Imitation): Given jointly normal a, x_1 and x_2, and non-decreasing cost function $C(\theta)$ such that $C'(0) < \sigma_a^2(1-\theta_1^*)$, Firm 2's demand for information is strictly positive, although strictly less than Firm 1's demand for information: $0 < \theta_2^* < \theta_1^*$. In this case, Firm 2's location choice rule can be described as "partial imitation" because Firm 2 chooses a location near, although not exactly the same as, Firm 1. Firm 2's choice of location depends in part on its private signal x_2. Partial imitation implies that y_2 and y_1 are closer than they would be if both firm's relied only on private information.

Figure 1 shows individually profit-maximizing levels of information (i.e., θ_1^* and θ_2^*), chosen by Firms 1 and 2 respectively, for the entire range of (inverse) information costs. The figure also shows aggregate profit, $\pi_1(y_1^*, \theta_1^*) + \pi_2(y_2^*, \theta_2^*)$, in the centralized (topmost curve) and decentralized cases (second curve from the top). The gap between the two aggregate profit curves, which varies non-monotonically over the range of information costs, provides one measure of the social cost of imitation. Comparison of this gap at the extremes versus middle of the range of information costs reveals an interesting non-monotonicity generated by the quadratic specification of $C(\theta)$: the social cost of imitation is negligible in environments where information is either very scarce or very abundant, and maximal in the intermediate range of information costs.

This result is different than what was reported above for the exponential cost function. For exponential costs, the cost parameter was bounded from above and, even for cost parameters where neither firm acquired information in the decentralized case, the central planner would always demand a minimum of $\theta_1 = 1/2$. Thus, the gap between centralized and decentralized aggregate profits was maximal where information costs were highest. In contrast, for the case of quadratic costs, if the cost parameter is large enough that neither firm demands private information in the decentralized case, then it does not pay for the central planner to acquire information either.

Another feature of Figure 1 is the non-monotonicity of θ_2^*. Whereas Firm 1 always demands more information as c falls, Firm 2's demand for information can go in either direction in response to a drop in the cost of information. When information is very expensive, neither firm acquires much information and both locate near the unconditional mean μ_a. Because Firm 1's information reduces the marginal benefit of Firm 2's information in all cases, Firm 2 acquires even less information than Firm 1, weighting Firm 1's location more than its own less precise private signal. At the other extreme when information is very cheap, Firm 1 acquires so much of the available information about good locations that Firm 2 receives very little marginal benefit from its own private information. In this case, the reduction in Firm 2's marginal benefit of information (thanks to the positive information spillover from observing Firm 1's previous location choice) dominates its increase in demand in response to lower information costs.

The variable θ_2^* provides one natural (inverse) measure of the magnitude of imitation, because it represents the extent to which Firm 2 collects private information (i.e., not imitating Firm 1). Alternatively, the magnitude of imitation could be quantified by the squared distance between the firms' locations:

$$(y_2^* - y_1^*)^2 = [\frac{(1-\theta_1)\theta_2}{1-\theta_1\theta_2}]^2(x_2 - \theta_1 x_1)^2, \tag{32}$$

which, in expectation, equals:

$$\mathrm{E}[(y_2^* - y_1^*)^2] = \theta_2(1-\theta_1)^2\sigma_a^2/(1-\theta_1\theta_2). \tag{33}$$

The distance between the firms' locations is small when θ_2 is near zero or θ_1 is near 1. The expected distance given by the square root of the expression in (33) reaches a maximum of 30 percent of the standard error of the ideal location a, measured by the parameter σ_a. Interpreting σ_a as the average distance of the ideal location from its unconditional mean, firms with the quadratic cost-of-information specification will locate, on average, closer to each other than the distance from the ideal location to its unconditional mean. Another feature of this specification of the model (not directly observable in Figure 1) is that the coordinated planner's solution always prescribes more total information than in the decentralized case. That is, the sum of quantities of information, $\theta_1 + \theta_2$, chosen by the planner is always greater than in the decentralized economy, with a maximum difference of around 0.35.

For a more detailed view of changes in the optimal values of θ_1, θ_2, and aggregate profit when comparing decentralized and centralized location choice, Figure 2 shows percentage changes in each of these variables over the same range of inverse information costs. The dotted line at the top of Figure 2 shows percentage change in the optimal choices of θ_1 when moving from the decentralized to centralized regime. The uniformly positive sign of these percentage changes indicates that the centralized solution always calls for Firm 1 to acquire more information than it would choose on its own. This makes sense, because Firm 1 cannot internalize the informational benefit it provides to Firm 2 in the decentralized regime.

In contrast, Figure 2 shows that Firm 2 usually acquires less information in the centralized regime, but not always. The cases where the central planner dictates that both firms acquire more information correspond to environments in which the cost of information acquisition is relatively large (σ_a^2/c near zero on the x-axis). The range of exogenous parameters in which both firms acquire more private information in the centralized regime reflects complementarity in the two firms' value of private information, which is nowhere present in the earlier specification with the exponential cost-of-information function. For quadratic private information costs and relatively high values of c, the marginal benefit of Firm 2's private information increases when the coordinated planner raises Firm 1's level of private information.[4] The solid line in Figure 2 is the percentage change in aggregate profit, which is always positive, because the planner optimally internalizes information externalities flowing from Firm 1 to Firm 2 to achieve greater aggregate profit.

2.5 Discrete choice in acquiring a signal of fixed precision

It is sometimes the case that firms cannot exert continuous control over the precision of private signals they acquire. For example, a consulting firm might offer a report on retail sites in a particular city for a fixed price. Similarly, marketing studies priced proportionally to sample size, holding the list of predictors fixed, would not provide purchasers of these services much choice over R^2. Another example is the decision to spend in-house to analyze publicly available census data, which could lead to different model specifications where the choice set for θ consists of a few discrete values of R^2 (without continuous control over R^2), because the list of regressors (e.g., available in census data) is exogenously fixed.

To investigate the consequences of discretizing the information acquisition decision,

[4] A related point concerns the non-monotonicity of Firm 2's response to a change in θ_1. This can be seen analytically in the indeterminate sign of $\frac{\partial \theta_2^*}{\partial \theta_1}$, observed by implicit differentiation of the characteristic equation (30) and noting that $\frac{\partial h(\theta_2)}{\partial \theta_2}$ is positive while $\frac{\partial h(\theta_2)}{\partial \theta_1}$ is of indeterminate sign.

this section considers an information market in which both firms make a binary decision of whether to acquire a privately available signal with fixed precision $\bar{\theta}$, at cost $c\bar{\theta}^2/2$. Note that the error terms in the two firms' private signals are independent, although the signals themselves are of course correlated and the R^2 of each is identical. This coarse parameterization implies that, without acquiring the private signal, Firm 1 faces expected costs of deviating from a equal to σ_a^2. In contrast, the decision to acquire the signal implies that Firm 1 faces expected costs of deviating from a equal to $\sigma_a^2(1-\bar{\theta})$. Thus, Firm 1's reduction in variance (i.e., increase in expected profit owing to decreased expected deviation from a) achieved as the result of acquiring the signal is $\sigma_a^2\bar{\theta}$. Firm 1 therefore decides to acquire the signal if and only if:

$$c\bar{\theta}^2/2 < \sigma_a^2\bar{\theta}, \quad \text{or} \quad \bar{\theta} < 2\sigma_a^2/c. \tag{34}$$

If Firm 1 acquires the signal and Firm 2 does not, then Firm 2 faces expected costs of deviating from a equal to $\sigma_a^2(1-\bar{\theta})$. If both firms acquire private signals, then Firm 2's expected cost of deviating from a equals $\sigma_a^2(1-\bar{\theta})/(1+\bar{\theta})$. Therefore, Firm 2's increase in expected profit by acquiring the signal is $\sigma_a^2\bar{\theta}(1-\bar{\theta})/(1+\bar{\theta})$, and it will decide to acquire the signal if and only if:

$$c\bar{\theta}^2/2 < \sigma_a^2\bar{\theta}(1-\bar{\theta})/(1+\bar{\theta}), \quad \text{or} \quad \bar{\theta}(1+\bar{\theta})/(1-\bar{\theta}) < 2\sigma_a^2/c. \tag{35}$$

Figure 3 shows all possible discrete-information-acquisition environments indexed by: (1) the cost of deviating from the ideal location a relative to the cost of private information acquisition σ_a^2/c, and (2) the precision of information $\bar{\theta}$. In the unshaded region (where the inequalities (34) and (35) fail to hold), neither firm acquires information, because the benefit of information relative to its cost is low. In the lightly shaded region (where (34) holds, but (35) does not), Firm 1 acquires the private signal and Firm 2 does not. In the darkly shaded region (where (34) and (35) both hold), both firms acquire private information. Thus, profit-maximizing firms in environments with binary choices over acquisition of information may choose to imitate first movers' locations rather than engaging in costly private information acquisition, just as in the previously considered case of environments with continuously valued choice sets for (and costs of) the quantity of information decision.

3 Discussion

One aim of this paper was to rationalize imitation in location choice as a profit-maximizing decision and begin to characterize environments in which the imitation heuristic works well in terms of social efficiency and where it does not. This investigation into a possible mismatch between the use of a location choice heuristic (which works well in high-information suburban and upper-income neighborhoods) and the structure of particular environments in which the imitation heuristic works poorly—low-information neighborhoods where profitable locations may persistently remain undiscovered—is proposed as a possible mechanism to (at least partially) explain the observed regularity of underdeveloped regions in central cities. There is a long and distinguished literature on spatial agglomerations of people and commerce (Christaller, 1933; Lösch, 1938; Zipf, 1949; Berry, 1961). Economists have advanced formal models of spatial organization, from Hotelling (1929) to Krugman (1993), and beyond.[5] Economists have produced a rich theoretical literature explaining why imitation is individually advantageous in various settings (Sinclair, 1990; Banerjee, 1992; Ellison and Fudenberg, 1995; Vega-Redondo, 1997; Bikhchandani, Hirshleifer and Welch, 1998; Schlag 1998, 1999; Offerman, Potters, and Sonnemans, 2002; Apesteguia, Huck, and Oechssler, 2003; Bosch-Domènech and Vriend, 2003;

[5] Boschma and Frenken (2007) provide an informative discussion of economic geography's institutional focus, which contrasts with new economic geography's neoclassical methodology that attempts to explain uneven distributions of economic activity in terms of dynamic processes driven by mobile factors of production.

Dutta and Prasad, 2004; Anderson, Ellison and Fudenberg, 2005), with empirical applications as well.[6] There is, however, very little in the relevant literatures bringing together the behavioral decision process of imitation and location choice.[7]

Substantial literatures in economics already provide models of location choice (Hotelling, 1929; Alonso, 1964; Muth, 1968) as well as spatial agglomerations and their statistical determinants (Kobrin, 1985; Konishi, 2005). The issue of ethnic enclaves and spatial patterns resulting from individual decisions about where to move also relates to the problem of imitation in firms' choices of location in terms of modeling technique (Gross and Schmitt, 2000; Huff, 1962). Not all of those who analyze spatial patterns focus on processes of agglomeration, of course. Some researchers argue that Hotelling-type economies should produce dispersion rather than concentration (d'Aspremont, Gabszewicz and Thisse, 1979). Similarly, Kain (1968) focuses on decentralization (i.e., the undoing of spatial agglomerations) and the unequal impacts of suburbanization on labor market opportunities for African Americans and other ethnic minorities. According to Glaeser, Hanushek and Quigley (2004), Kain's spatial explanations for persistently high unemployment in minority neighborhoods played a large role in raising awareness among economists of disparities based on race

[6] Rodgers (1952) describes dramatic spatial concentrations of steel production in the U.S., and the possibility that these concentrations might undermine national security. Similarly, Rees (1978) describes spatial concentrations in the rubber industry. Mansfield (1961) provides empirical evidence linking firms' decisions to introduce new techniques of production to the proportion of firms already using that technique, in line with widely used gravity models in the social sciences. Geertz (1978) observes spatial agglomeration according to product type in bazaars in Algeria. Walcott (1999) finds agglomerations of biotech firms in Atlanta, suggestive of imitation as a strategy for coping with scarcity of information. Fairen (1996) argues that imitative behavior may best explain why automobile manufacturers produce very similar models of cars. And Seamans (2006) investigates spatial clustering in the cable television industry.

[7] One exception is the experimental Hotelling economy analyzed by Camacho-Cuena et al (2005), which demonstrates that spatial agglomerations can occur in the lab, but not always as the result of decision-making processes that follow the standard model. The international finance literature, too, frequently studies interdependencies among firms' investment decisions (Kindleberger, 1983), and imitation is an established hypothesis concerning important choice variables in international trade (Schmitt, 1995).

and ethnicity.

In contrast, the administrative management literature has devoted considerable attention to imitation in location choice (Guillen, 2002; Haunschild, 1993; Haveman, 1993). Descriptive models in this literature focus on how exit and entry of other firms allow managers to make inferences about expected levels of profitability, leading to correlated entry and exit decisions across firms (Baum, Li and Usher, 2000; Miner and Haunschild, 1997), which is consistent with the present paper's model of imitation in location choice. Another motive for imitation cited in this literature is to conform with social norms (Abrahamson and Rosenkopf, 1993); according to this hypothesis, it may pay off to imitate peer decisions even in the absence of extrinsic motives for adopting strategies that peer firms have adopted. Concern over legitimacy is another reason why managers may eschew independent approaches in favor of imitation of peers whose actions are perceived as legitimate (DiMaggio and Powell, 1983; Fligstein, 1985; Miner and Haunschild, 1997). In many of these models in which social forces motivate imitation, the more predictable the environment is, the stronger the incentive to imitate (Argote, Beckman and Epple, 1990), which is opposite of the model presented in this paper.

Empirical accounts from interview studies (Schwartz, 1987, 2004; Bewley, 1999; Berg, 2014) favor the position that firms rely on simplifying rules of thumb, or heuristics. Wiessbourd (1999) reports that businesses in Chicago use simple rules of thumb to decide on locations; these rules of thumb tend to work well in environments with lots of information but also tend to reinforce negative perceptions about stigmatized neighborhoods, which leaves profitable opportunities unexploited in low-information environments. Anecdotal evidence corroborates the potential for inefficient spatial patterns to leave profitable locations underutilized as theorized in this paper. For example, according to one individual involved in location decisions for the German discount supermarket chain Lidl, its location decisions follow a simple rule of thumb: build a store wherever Aldi (Lidl ' s primary competitor) has a location (Scheibene, 2007, personal communication). Berg's (2014) interview data include accounts from business owners who avoid neighborhoods without other retailers already in operation; estimates of self-reported profitability as a function of information gathering and sizes of locational consideration sets suggest that imitation is positively associated with performance.

Given that firms in the real world condition location decisions on the observed locations of other firms, it is natural to investigate whether imitation can be rationalized within the profit maximizing framework. The model presented in Section 2 addresses this problem and the perhaps more important issue from a policy perspective of social efficiency in low-information environments that are badly matched to imitation heuristics in location choice. The central question is whether underutilization of urban sites for commercial activity is the result of a process in which firms first consider those sites and wind up deciding they are unprofitable, or whether the imitation heuristic, which is suitable for information-rich investment environments where business activity is already present, leads to inefficient clustering and systematic underutilization. The magnitude of the problem of abandoned property in US central cities, for example, appears in the economics literature at least as early as the 1970s (Stegman and Rasmussen, 1980). Caplin and Leahy (1998) provide a general rationalization for abandonment or underutilization that, in my view, deserves more attention from local economic development teams. The model presented above has the advantage of identifying conditions about the availability of information in the external environment that are necessary for tension to exist between individual profit maximization and social efficiency caused by imitation in location choice.

4 Conclusion

The model presented in this paper draws on empirical accounts of spatial concentration in well-established retail centers of affluent suburbs by firms that overlook profitable opportunities in urban neighborhoods (Berg, 2014; Helling and Sawicki, 2003; Sabety and Carlson, 2003; Francica, 2000; Weissbourd, 1999). The model provides at least an initial step toward better understanding opportunistic information sharing that leads to imitation in location choice. The model demonstrates that imitation is consistent with expected profit maximization, although imitation usually results in lower aggregate profits than would be achieved by a coordinated decision maker who internalizes the positive information externality flowing from early to later movers. This finding suggests a new motive for chain retailers and multi-location owners to grow large enough to capture such informational spillovers. Firms are assumed to be identical except that later movers can make use of earlier movers' locations as conditioning information and save on private expenditures on information acquisition.

Imitation in location choice is not uniformly bad for aggregate efficiency. There is a genuine positive externality flowing from early to later movers. Imitation usually helps exploit this positive externality to some extent, but not fully enough to achieve the efficiency that coordinated location choice achieves. As shown in Figure 2, over most of the range of the cost-of-information parameter c, the coordinated planner chooses to acquire more information for Firm 1 and less for Firm 2 than in decentralized expected profit maximization. Thus, in this parameter range, the central planner fully exploits the positive externality by increasing, not reducing, the extent of imitation. When c is very large, however, the central planner requires that both firms acquire additional private information, implying that a reduction in imitation is needed to achieve social efficiency. This case might argue for public provision of neighborhood-level demographic and crime information that can be used to estimate revenues and costs, or perhaps direct subsidies for first movers into neighborhoods seeking (re-)development.

Whether imitation is consistent with the full utilization of profitable locations depends on the informational environment. Suburban areas with well-established concentrations of retail (compared with that of low-income neighborhoods) transmit far greater flows of information to new entrants regarding where profitable locations are to be found. Insofar as suburbs enjoy well-defined land use rules and relatively liquid markets for efficiently channeling development capital to profitable locations, the suburban environment is informationally abundant, in the sense that it is cheap to discover where profits are currently earned. The model suggests that, in an informationally abundant environment, the imitation heuristic is both individually effective and socially useful. In contrast, when information is expensive or scarce, imitation remains individually effective but comes at a relatively large cost in terms of social efficiency.

A general feature of the model is that firms would always prefer to be second mover and, if the cost of time is low enough, would choose to wait rather than move first, consistent with the idea of spatial lock-in and longstanding underutilization of potentially profitable locations in central cities. Second movers always enjoy greater expected profit because freely available observation of the first mover's location results in lower total information costs over the entire parameter space. This theoretical result suggests a motive for first movers to try to become large enough to internalize informational spillovers and exhaust all monopoly rents associated with a particular location—a motive that may apply to the phenomenon of big box retail and highly coordinated location decisions that involve a small number of very large first movers rather than a long sequence of smaller movers.

Policies aimed at sparking business development in poor neighborhoods typically rely on the standard economic model of profit-maximization and its assumption that firms conduct extensive (if not exhaustive) search over large consideration sets before choosing where to invest. Empirical work, however, points to limitations on firms' process of populating consideration sets with candidate locations and their ability to make reliable spatial predictions based on expected profit. Different policy approaches are called for if firms' decision processes diverge from the standard model and are better represented by a simple decision tree that eliminates neighborhoods from consideration based on a single reason—for example, because there are no other firms already there, or because of statistically unsubstantiated fears about high crime, or because of managers' inherent preferences for areas that are personally familiar to them. Future work detailing the size and contents of firms' consideration sets when making location decisions and more veridical description of the actual decision processes they employ in location choice would be useful.

Milton Friedman's as-if methodology argues that it is acceptable to use an incorrect model of consumers' and firms' decision processes as long as that model predicts accurately. As-if models, when used to design local economic development policies aimed at attracting business to neighborhoods with virtually no visible commerce, may get important predictions wrong. For example, modest tax incentives offered to firms that locate in urban zones targeted by policy makers would, according to the informational structure that motivates imitation in the model, do little to attract new entrants. The model suggests that a more powerful mechanism for motivating firms to consider entry into parts of cities currently without much in the way of formal commerce would be new information flows based on highly visible and successful first movers.

References

Abrahamson, E., and Rosenkopf, L. (1993). Institutional and competitive bandwagons: Using mathematical modeling as a tool to explore innovation diffusion. Academy of Management Review, 18, 487-517.

Alonso, W. (1964). Location and land use: Toward a general theory of land rent. Cambridge, MA: Harvard University Press.

Anas, A., and Rhee, H. J. (2007). When are urban growth boundaries not second-best policies to congestion tolls?. Journal of Urban Economics, 61(2), 263-286.

Anderson, R. M., Ellison, G., and Fudenberg, D. (2005). Location choice in two-sided markets with indivisible agents. HIER Working Papers 2056, Harvard University.

Andersson, F., Burgess, S., and Lane, J. I. (2007). Cities, matching and the productivity gains of agglomeration. Journal of Urban Economics, 61(1), 112-128.

Apesteguia, J., Huck, S., and Oechssler, J. (2003). Imitation—Theory and experimental evidence. CESifo Working Paper Series No. 1049, University of Munich.

Argote, L., Beckman, S. L., and Epple, D. (1990). The persistence and transfer of learning in industrial settings. Management Science, 36, 140-154.

Banerjee, A. V. (1992). A Simple Model of Herd Behavior. Quarterly Journal of Economics 107, 797-818.

Baum, J., Li, S. X., and Usher, J. (2000). Making the next move: How experiential and vicarious learning shape the locations of chains' acquisitions. Administrative Science Quarterly, 45(4), 766-801.

Berg, N. (2014). Success from satisficing and imitation: Entrepreneurs location choice and implications of heuristics for local economic development. Journal of Business Research, 67(8), 1700-1709.

Berg, N. and Hoffrage, U. (2008). Rational ignoring with unbounded cognitive capacity. Journal of Economic Psychology, 29, 792-809.

Berg, N., Hoffrage, U., and Abramczuk, K. (2010). Fast Acceptance by Common Experience: FACE-recognition in Schellings model of neighborhood segregation. Judgment and Decision Making, 5(5), 391-410.

Bergsman, J., Greenston, P., and Healy, R. (1972). The agglomeration process in urban growth. Urban Studies, 9, 263-88.

Berry, B. J. L. (1961). City size distributions and economic development. Economic Development and Cultural Change, 9, 573-588.

Bewley, T. F. (1999). Why wages don't fall during a recession. Cambridge, MA: Harvard University Press.

Bikhchandani, S., Hirshleifer, D., and Welch, I. (1998). Learning from the behavior of others: Conformity, fads and information cascades. Journal of Economic Perspectives, 12(3), 151-170.

Bosch-Domènech, A., and Vriend, N. J. (2003). Imitation of successful behavior in Cournot markets. The Economic Journal, 113, 495-524.

Boschma, R. A., and Frenken, K. (2007). Applications of evolutionary economic geography. In Frenken, K. (Ed.), Applied Evolutionary Economics and Economic Geography. Cheltenham: Edward Elgar.

Boulding, K. (1996). Economic Analysis. Vol. I, Microeconomics. 4th Ed. New York: Harpers.

Bray, T. (2007). Dallas is not as dangerous as you think: The crime we have is bad, but it's concentrated. Dallas Morning News, April 6, Viewpoints.

Brueckner, J. K., and Rosenthal, S. S. (2005). Gentrification and neighborhood housing cycles: Will America's future downtowns be rich?. CESifo Working Paper Series No. 1579. Accessed October 28, 2007, at http://ssrn.com/abstract=852525.

Camacho-Cuena, E., Garcia-Gallego, A., Georgantzis, N., and Sabater-Grande, G. (2005). Buyer-seller interaction in experimental spatial markets. Regional Science and Urban Economics, 35, 89-108.

Caplin, A., and Leahy, J. (1998). Miracle on Sixth Avenue: Information externalities and search. Economic Journal, 108, 60-74.

Chang, S. J. (1995). International expansion strategy of Japanese firms: Capability building through sequential entry. Academy of Management Journal, 38, 383-407.

Chang, S. J., and Rosenzweig, P. M. (2001). The choice of entry mode in sequential foreign direct investment. Strategic Management Journal, 22, 747-776.

Christaller, W. (1933). Die zentralen Orte in Sueddeutschland. Jena, Germany. Gustav Fischer. [trans. Baskin, C. W. (1996). Central Places in Southern Germany. Englewood Cliffs, NJ: Prentice Hall].

Chung, W. (2001). Mode, size, and location of foreign direct investments and industry markups. Journal of Economic Behavior and Organization, 45, 185-211.

Cyert, R. M., and March, J. G. (1963). A behavioral theory of the firm, 2nd Ed. Cambridge, MA: Blackwell Business.

d'Aspremont, C., Gabszewicz, J. J. and Thisse, J. F. (1979). On Hotelling's stability in competition. Econometrica, 47, 1145-1150.

DiMaggio, P. J., and Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. American Sociological Review, 103, 1-37.

Dudey, M. (1990). Competition by choice: The effect of consumer search on firm location decisions. American Economic Review, 80, 1092-1104.

Dudey, M. (1993). A note on consumer search, firm location choice, and welfare. Journal of Industrial Economics, 41, 323-331.

Dutta, J., and Prasad, K. (2004). Imitation and long run outcomes. Berkeley Electronic Press, 4(1), 1163-1163.

Eaton, B. C., and Lipsey, R. G. (1976). The non-uniqueness of equilibrium in the

Löschian location model. American Economic Review, 66, 77-93.

Eaton, B. C., and Lipsey, R. G. (1979). Comparison shopping and the clustering of homogeneous firms. Journal of Regional Science, 19, 421-435.

Eeckhoudt, L., Godfroid, P., and Gollier, C. (2001). Multiple risks and the value of information. Economic Letters, 73, 359-365.

Ellison, G., and Fudenberg, D. (1995). Word of mouth communication and social learning. Quarterly Journal of Economics, 110, 93-126.

Fairen, V. (1996). A replicator theory model of competition through imitation in the automobile market. Journal of Economic Behavior and Organization, 29, 141-157.

Fischer, J. H., and Harrington, J. E., Jr. (1996). Product variety and firm agglomeration. The RAND Journal of Economics, 27, 281-309.

Fligstein, N. (1985). The spread of the multidivisional form among large firms, 1919-1979. American Sociological Review, 50, 377-391.

Francica, J. (2000). Location analysis tools help Starbucks brew up new ideas. Business Geographics, 8, 32-33.

Geertz, C. (1978). The bazaar economy: Information and search in peasant marketing. American Economic Review, 68, 28-32.

Gigerenzer, G., and Selten, R. (Eds.) (2002). Bounded rationality: The adaptive toolbox. Cambridge, MA: MIT Press.

Gigerenzer, G., Todd, P. M., and The ABC Research Group. (1999). Simple heuristics that make us smart. New York: Oxford University Press.

Glaeser, E., Hanushek, E., and Quigley, J. (2004). Opportunities, race, and urban location: The influence of John Kain. HIER Working Paper 2030, Harvard University.

Gross, D., and Schmitt, N. (2000). Do birds of a feather flock together? Immigration flows and cultural clustering in host countries. Working Paper, Simon Fraser

University.

Guillen, M. (2002). Structural inertia, imitation and foreign expansion: South Korean firms and business groups in China, 1987-1995. Academy of Management Journal 2(4), 389-421.

Haunschild, P. R. (1993). Interorganizational imitation: The impact of interlocks on corporate acquisition activity. Administrative Science Quarterly, 38, 564-592.

Haveman, H. A. (1993). Follow the leader: Mimetic isomorphism and entry into new markets. Administrative Science Quarterly, 38, 564-592.

Helling, A., and Sawicki, D. (2003). Race and residential accessibility to shopping and services. Housing Policy Debate, 14, 69-101.

Helsley, R. W., and Strange, W. C. (1999). Gated communities and the economic geography of crime. Journal of Urban Economics, 46(1), 80-105.

Hilton, R. (1981). Determinants of information value. Management Science, 27, 57-64.

Hotelling, H. (1929). Stability in competition. Economic Journal, 39, 41-57.

Huff, D. L. (1962). A note on the limitations of interurban gravity models. Land Economics, 38, 64-66.

Kain, J. F. (1968). Housing segregation, Negro employment and metropolitan decentralization. Quarterly Journal of Economics, 82, 175-197.

Kanemoto, Y. (1990). Optimal cities with indivisibility in production and interactions between firms. Journal of Urban Economics, 27, 46-59.

Kindleberger, C. P. (1983). International banks as leaders or followers of international business. Journal of Banking and Finance, 7, 583-595.

Kobrin, S. J. (1985). Diffusion as an explanation of oil nationalization (or the domino effect rides again). Journal of Conflict Resolution, 29, 3-32.

Kogut, B. (1983). Foreign direct investment as a sequential process. In Audretch, D.

and Kindleberger, C.P. (Eds.), The Multinational Corporation in the 1980s (pp. 38-56). Cambridge, MA: M.I.T. Press.

Konishi, H. (2005). Concentration of competing retail stores. Journal of Urban Economics, 58, 488-512.

Krugman, P. (1993). On the number and location of cities. European Economic Review. 37, 293-298.

Lösch, A. (1938). The nature of economic regions. Southern Economic Journal, 5, 71-78.

Mansfield, E. (1961). Technical change and the rate of imitation. Econometrica, 29, 741-766.

March, J. G. (1988). Decisions in organizations. New York: Blackwell.

Miner, A. S., and Hanuschild, P. R. (1997). Modes of interorganizational imitation: The effects of outcome salience and uncertainty. Administrative Science Quarterly, 42, 472-500.

Muñiz, I., and Galindo, A. (2005). Urban form and the ecological footprint of commuting: The case of Barcelona. Ecological Economics, 55, 499-514.

Muth, R. (1968). Cities and housing. Chicago: University of Chicago Press.

Noble, J., Todd, P. M., and Tuci, E. (2001). Explaining social learning of food preferences without aversions: An evolutionary simulation model of Norway rats. Proceedings of the Royal Society of London B: Biological Sciences, 268 (1463), 141-149.

Offerman, T., Potters, J., and Sonnemans, J. (2002). Imitation and belief learning in an oligopoly experiment. Review of Economic Studies, 69, 973-997.

Prescott, E. C., and Visscher, M. (1977). Sequential location among firms with foresight. The Bell Journal of Economics, 8, 378-393.

Rees, J. (1978). On the spatial spread and oligopolistic behavior of large rubber companies. Geoforum, 9, 319-30.

Rodgers, A. (1952). Industrial inertia—A major factor in the location of the steel industry in the United States. Geographical Review, 42, 56-66.

Rosenthal, S. S., and Strange, W. C. (2001). The determinants of agglomeration. Journal of Urban Economics, 50(2), 191-229.

Sabety, P., and Carlson, V. (2003). Using information to drive change: New ways of moving markets. Washington, DC: Brookings Institution.

Schlag, K. (1998). Why imitate, and if so, how? A boundedly rational approach to multi-armed bandits. Journal of Economic Theory, 78, 130-56.

Schlag, K. (1999). Which one should I imitate? Journal of Mathematical Economics, 31, 493-522.

Schmitt, N. (1995). Product imitation, product differentiation and international trade. International Economic Review, 36, 503-608.

Schwartz, H. (1987). Perception, judgment and motivation in manufacturing enterprises: Findings and preliminary hypotheses from in-depth interviews. Journal of Economic Behavior and Organization, 8, 543-65.

Schwartz, H. (2004). The economic analysis underlying corporate decision making: What economists do when confronted with business realities. Business Economics, 39, 50-59.

Seamans, R. (2006). How does clustering by cable TV firms affect technology diffusion? Working Paper, University of California-Berkeley.

Simon, H. A. (1954). Bandwagon and underdog effects and the possibility of election predictions. Public Opinion Quarterly, 18, 245-253.

Simon, H. A. (1955). A behavioral model of rational choice. The Quarterly Journal of Economics, 69, 99-118.

Sinclair, P. J. N. (1990). The economics of imitation. Scottish Journal of Political

Economy, 37, 113-144.

Stegman, M. A., and Rasmussen, D. W. (1980). Neighborhood Stability in Changing Cities. American Economic Review, 70, 415-419.

Townroe, P. M. (1991). Rationality of the industrial location decision. Urban Studies, 28, 383-392.

Turner, M.A. (2007). A simple theory of smart growth and sprawl. Journal of Urban Economics, 61, 21-44.

Vega-Redondo, F. (1997). The evolution of Walrasian behavior. Econometrica, 65, 375-384.

Verdier, T., and Zenou, Y. (2004). Racial beliefs, location, and the causes of crime. International Economic Review, 45(3), 731-760.

Walcott, S. M. (1999). High tech in the deep south: Biomedical firm clusters in metropolitan Atlanta. Growth and Change, 30(1), 48-74.

Weissbourd, R. (1999). The market potential of inner-city neighborhoods: Filling the information gap. Washington, DC: The Brookings Institution.

Willinger, M. (1989). Risk aversion and the value of information. Journal of Risk and Insurance, 56(2), 320-328.

Wolinsky, A. (1983). Retail trade concentration due to consumers' imperfect information. Bell Journal of Economics, 14, 275-282.

Zipf, G. K. (1949). Human behavior and the principle of least effort. Cambridge, MA: Harvard University Press.

Figure 1: Centralized aggregate profit envelope (dash-dotted line), aggregate profit under individual choice (solid line), Firm 1's (dotted) and Firm 2's (starred) private information acquisition, as a function of inverse information cost (from most to least expensive)

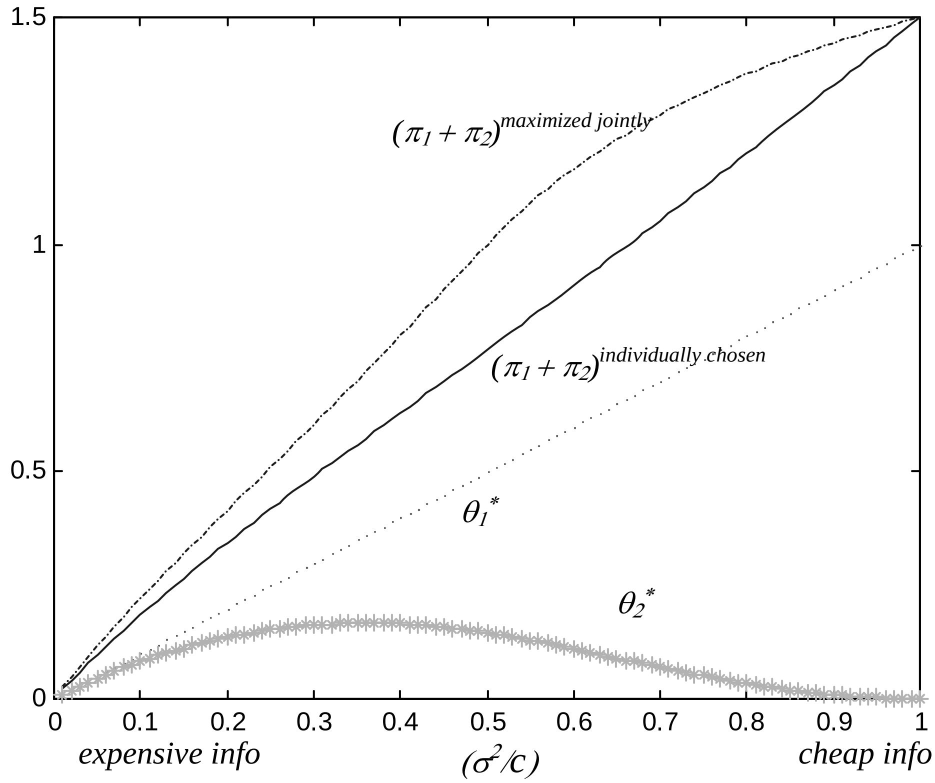

Figure 2: From decentralized to centralized regimes: Percentage change in aggregate expected profit (solid line), Firm 1's information acquisition (dotted), and Firm 2's information acquisition (starred), as a function of inverse information cost

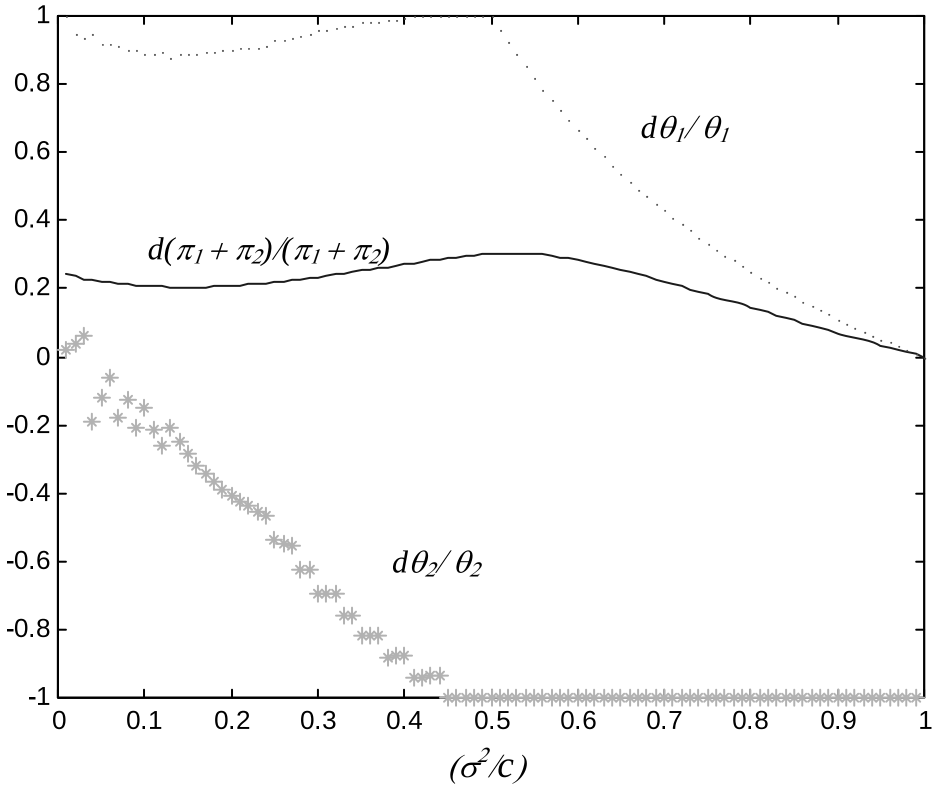

Figure 3: Binary information acquisition decisions as a function of inverse cost of information (x-axis) and the fixed precision of the private signal (y-axis): Environments in which neither firm acquires private information (unshaded), Firm 1 acquires private information and Firm 2 does not (lightly shaded), and both firms acquire private information (darkly shaded)

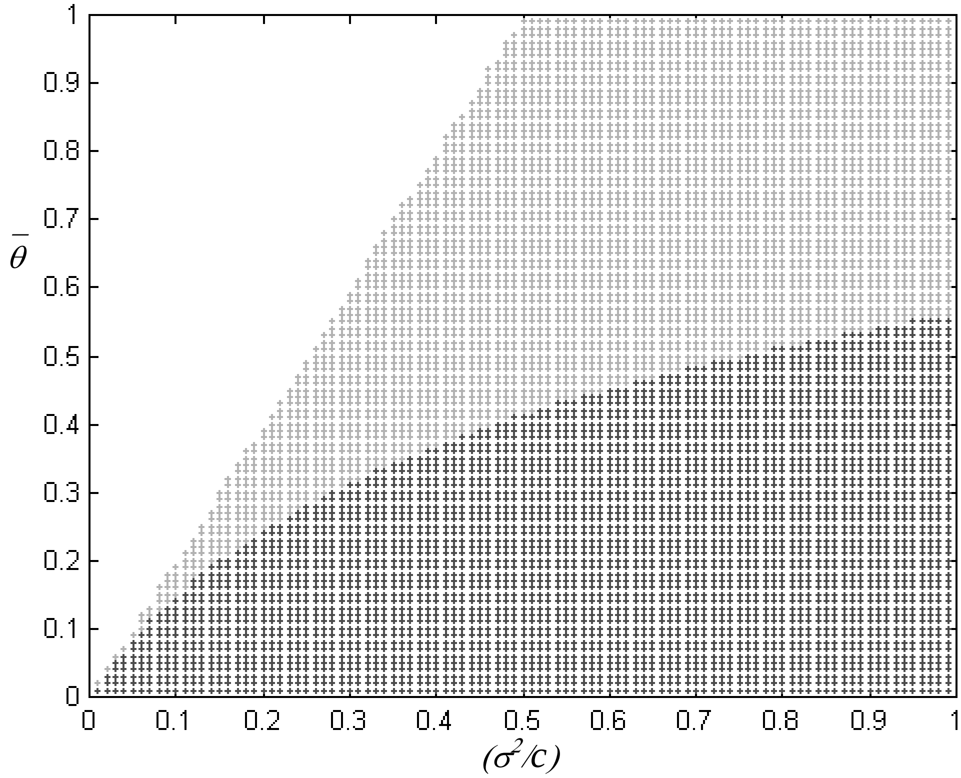

Figure 3 shows a partition of the universe of possible environments, indexed by the inverse relative cost of information and fixed precision of the available signal. Firms make discrete choices of whether to acquire the signal. Whether firms acquire the signal depends on the signal's cost, its (fixed) quality, and--most importantly--whether the firm is first mover or not. In the unshaded region, neither firm acquires information because costs of information are high relative to the cost savings in deviating from the ideal location *a*. In the darkly shaded region, both firms acquire information because information costs are relatively low. In the lightly shaded region, however, Firm 1 acquires information but Firm 2 does not. This difference is purely the result of first- and second-mover status, as Firm 2 would have acquired the signal had it not been able to freely extract information by observing Firm 1's location.