Technology Diffusion and Market Structure: Evidence from Infertility Treatment Markets

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Abstract: We study how market structure influenced the diffusion of new treatment technology (ICSI) among U.S. fertility clinics that performed *in vitro* fertilization (IVF). We find that competitive (i.e., non-monopoly) markets were more likely to have a clinic that offered ICSI than monopoly markets. Our results account for the potential endogeneity of market structure with respect to entry-foreclosing technology adoption and unobserved market characteristics that might increase the return from offering ICSI. We also provide evidence that ICSI diffused faster to competitive markets because the returns from the new technology were greater there. Early-adopting clinics in competitive markets experienced a significant increase in size, while early-adopting monopoly clinics did not. However, monopoly clinics that adopted ICSI soon after its invention were more likely to delay the entry of rival firms than monopolists that adopted ICSI later.

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I. Introduction

It is widely accepted that technological advances in production and the invention of new products have substantial effects on the surplus generated in markets. What has been more controversial is what type of market structure yields the fastest technological progress or diffusion of new products. In an early and prominent exchange in this debate, Schumpeter [1943] argued that monopoly firms are more likely engage in research and development (R&D) activity than competitive firms, while Arrow [1962] took the opposite view.[1] Schumpeter contended that large firms with the ability to capture a substantial portion of newly-created surplus have the greatest return from R&D, while Arrow noted that competitive firms may have a stronger incentive to innovate because the benefit of obtaining (some) market power is great relative to the competitive status quo.

This tension, between a monopoly's ability to capture surplus and a competitive firm's drive to out-perform its rivals, resonates in related literatures on the diffusion of new cost-saving technologies and the introduction of new products. In the literature on technology adoption, Fudenberg and Tirole [1985] were the first to argue that duopoly firms' business-stealing and preemption incentives will lead one of the competing firms to employ a cost-saving technology before a monopolist would. This contrasts with Reinganum's [1981] result that the relative speed of diffusion in monopoly and competitive markets depends on the parameters of the decision problem.[2] In differentiated products markets, the standard incentive for firms to soften price competition may accelerate the introduction of new products in relatively competitive markets. However, a monopolist's ability to price discriminate within a vertically-differentiated product menu may provide a greater return from offering a new product.[3] Both literatures – on the adoption of cost-reducing technologies and on product menus – predict that a monopoly incumbent firm facing an entry threat may use a new technology or introduce a new product earlier than an unthreatened monopolist.

In this paper we draw on intuition from the technology adoption and product differentiation literatures to analyze how market structure affects the diffusion of a new technology in U.S. markets for infertility treatment. There are four main reasons why infertility

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[1] For additional discussion of these issues, see Cohen and Levin's [1989] survey of innovative activity and market structure.

[2] The difference in the results of Reinganum [1981] and Fudenberg and Tirole [1985] is due to different assumptions on the timing of the technology adoption game.

[3] See Tirole [1988] for additional discussion of product differentiation and price discrimination theory.

treatment is a compelling area in which to study competition's impact on technology diffusion. First, the industry has experienced rapid technological change. Beginning with the birth of the first "test-tube baby" in 1978, the class of advanced treatments called Assisted Reproductive Technology (ART) has grown rapidly. By 2001, 1% of children born in the U.S. were conceived using the leading ART method, *in vitro* fertilization (IVF).[4] Second, there is substantial policy interest in expanding access to infertility treatment.[5] Despite the growing use of IVF, relatively few of the approximately 6 million American couples reporting reproductive problems actually use ART. This is primarily due to the high cost of IVF ($10,000-$15,000 per attempt), its low success rate (27% in 2001), and the fact that treatment expenses are generally paid out-of-pocket by most couples. Therefore, the diffusion of a new technology that improves success rates or lowers costs is likely to increase access to treatment. The third reason to study ART markets follows from the out-of-pocket expenses of treatment. This is a health care market in which consumers (patients) and firms (clinics) make their choices without substantial regulatory or institutional intervention, so we expect market activity to be informative about technology diffusion in general, i.e., outside of health care markets. Finally, the structure of ART markets is frequently concentrated but varies by location and time. We use this variation in market structure to identify the effect of competition among clinics on the timing of technology adoption.

We focus on the diffusion of intracytoplasmic sperm injection (ICSI), a technology that has been hailed by infertility experts as the greatest advance in ART since the first IVF birth.[6] ICSI was invented in 1991 as a supplement to IVF. Within IVF, sperm and an egg are combined in a laboratory to fertilize the egg and generate an embryo, which is transferred back to the patient. ICSI allows this process to occur with greater precision by isolating and injecting a single sperm into the egg. The use of ICSI improves the probability of a successful treatment, which may decrease the expected cost of obtaining a child through ART and therefore expand the use of IVF within the population of potential patients. Our data on ICSI begin in 1992 when the procedure was first used commercially in 1% of all IVF treatments and available in 22% of all clinics. In the final year of our data, 2001, 88% of all clinics offered ICSI and the technology

[4] ART and IVF have become nearly synonymous, and throughout this paper we use the terms interchangeably except when discussing different forms of ART.
[5] See Hamilton and McManus [2005] for an overview of policy interest in ART markets.
[6] See Schoolcraft [1999].

was available to patients in 98% of all markets (U.S. metro areas). Patients typically pay about $1,500 to add ICSI to IVF and in 2001 half of all IVF treatments included ICSI. The dominant pattern in the data is that clinics in non-monopoly markets offered ICSI earlier than monopolies. Throughout the paper we refer to non-monopoly markets as "competitive."

Clinics that consider offering ICSI will weigh the benefits (and possibility) of business-stealing, preemption, product differentiation, and price discrimination against the technology's adoption costs, which primarily come from the purchase of specialized equipment and the need to hire an embryologist with expertise in ICSI. The nature of pricing and conduct in the industry will ultimately determine whether competition or monopoly leads to the more rapid diffusion of ICSI to a market. The existing empirical literature on firms' technology adoption decisions is similarly mixed. Prior research has found that additional competition may speed the diffusion of a new technology, as in Levin *et al*.'s [1987] study of supermarket check-out scanners, or slow diffusion, as in Hannan and McDowell's [1984a, 1985b] studies of automated teller machines (ATMs) and Genesove's [1999] study of newspaper printing presses.[7] However, it is not clear whether these results reflect the variety of predictions possible for technology diffusion, or whether the findings are strongly influenced by the authors' empirical specifications. Much of the previous research on market structure and technology diffusion includes an assumption that the level of competition in a market is exogenous to the diffusion process.

With this paper, we make two main contributions to the industrial organization literature on new technologies. First, we estimate how a change in market structure from monopoly to non-monopoly affects the probability that ICSI is available in a market. We find that competition among clinics accelerated the diffusion of ICSI. The inference is robust to concerns that: 1) unobserved market characteristics shift both market structure and the return from ICSI adoption, 2) entry foreclosure incentives lead to the simultaneous determination of ICSI diffusion and IVF market structure, and 3) adoption occurs earlier in competitive markets because the clinics there are more likely to adopt regardless of market structure. We also find that diffusion of ICSI to California was delayed by regulation there which favored an alternative ART treatment process that was found to be inferior to IVF. This is an important piece of evidence against regulation that "picks winners" among new technologies.

[7] There is also a substantial literature on technology diffusion which does not focus on market structure's role. For examples, see Oster [1982] or Rose and Joskow [1984].

The second main contribution of this paper is our analysis of clinic performance in the period *after* most ICSI adoption activity. Clinics that were among the first adopters of ICSI experienced an immediate increase in size and market share following their introduction of the technology. Clinic growth was greatest in non-monopoly markets, which supports the notion that ICSI diffused earlier to the markets with the greatest returns to early adopters. However, we also present evidence that monopoly clinics with substantial ICSI experience were successful in delaying the entry of rival firms.

The rest of this paper is organized as follows. In the next section (II) we describe in more detail the relationship between this research and previous studies. Section III contains an overview of ART procedures and the variation in state regulation of infertility treatment. We review the data in Section IV, and the main empirical analysis of ICSI diffusion is in Section V. In Section VI we provide evidence on the benefits to clinics from being among the earliest adopters of ICSI. Our conclusions are in Section VII.

II. Related Literature

In this section we discuss the empirical implications of theoretical models of technology adoption and product differentiation for market structure's impact on ICSI diffusion. In addition, we briefly review related research on the role of competition in medical markets. In a model of firms' adoption of a new cost-reducing technology, Reinganum [1981] finds that a change in market concentration may speed or slow technology adoption if firms make once-and-for-all commitments to their eventual adoption dates. Fudenberg and Tirole [1985] study situations in which firms may choose at any moment to take on a new technology, and find that the first duopoly firm to adopt will do so before a monopolist would have adopted. This is due to a combination of business-stealing incentives for competing firms and the desire to preempt technology adoption by a rival firm. The differing predictions of Reinganum and Fudenberg-Tirole follow from the strategies permitted in each model. We suspect that the Fudenberg-Tirole "closed loop" (sub-game perfect) equilibrium is more closely related to activity in ART markets, since ICSI was adopted throughout the period 1992-2001 by clinics that were founded both before and after ICSI's invention.[8] Riordan [1992] extends the Fudenberg-Tirole model to demonstrate that regulation of prices or entry can affect the timing of technology adoption. This is important to the present paper since U.S. infertility treatment markets vary in how regulations may affect overall demand for IVF.

The incentives that can drive a duopolist to adopt a cost-reducing technology earlier than a monopolist may also compel an incumbent firm with market power (generally described as a monopolist) facing an entry threat to adopt the technology before an unthreatened firm. In adopting a new technology, the incumbent may effectively limit the prospective new firm's choices to entry with the old technology or no entry at all, and the second option may be preferred. This is an important consideration which complicates our empirical objective of estimating how market structure affects ICSI diffusion. Entry foreclosure incentives suggest a causal relationship that flows from a firm's technology choice to market structure. The prior empirical research on market structure's effect on technology adoption, cited in the Introduction, has not focused on entry foreclosure, and additionally takes market structure to be determined exogenously.

While the main predictions from the theory of technology adoption concern cost-reducing innovations, the introduction of ICSI created a new service rather than simply reducing the cost of treatment. Therefore, we also draw intuition from the literature on product differentiation and multi-product firms. The theoretical contributions in these areas do not contain clear predictions of whether an oligopoly market will contain a more diverse product menu than a monopoly market. Studies of monopoly and duopoly nonlinear pricing predict that a monopolist offers a menu of products with greater quality variety than in duopolists' menus.[9] However, the monopolist's menu is typically extended at the bottom of the product quality spectrum, not the top (as in the case of ICSI).[10] In contrast to monopoly firms that may offer broad product menus to facilitate price discrimination, the desire to soften price competition may drive competing IVF clinics to seek vertical differentiation opportunities. Analogous to the case of a monopolist adopting a cost-reducing technology in order to prevent entry, predictions of market structure's

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[8] We interpret this pattern in the data to indicate that clinics did not have to commit to a schedule of ICSI adoption soon after the technology was invented. Instead, old and new clinics could choose to introduce the service relatively rapidly, soon after they decided that such an action was beneficial.

[9] See Champsaur and Rochet [1989] and Stole [1995] for examples.

[10] When a price-discriminating monopolist is subject to a minimum quality standard that places a binding floor on the lowest-quality product it can offer, Besanko *et al.* [1987] show that this will not affect the design or availability of high-quality products offered to consumers with the strongest demand.

effect on product differentiation may be further complicated by the incentive of an incumbent firm to engage in a product proliferation strategy in order to deter entry.[11]

Empirical evidence on how competition affects firms' choices of product quality is limited.[12] Mazzeo [2003] establishes that air travel departures are less likely to be delayed on routes with competition, and Hoxby [2000] finds that public school quality is higher in areas with more school districts. The empirical study that is most similar to the present paper is Cohen and Mazzeo's [2005] consideration of how competition among different types of banks affects the number of branches a bank offers. Cohen and Mazzeo use data from a cross-section of small banking markets to find that bank branching, which is taken to be a measure of quality, may increase or decrease with the amount of competition in a market. As in the present paper, the authors are concerned that unobserved market characteristics and foreclosure incentives may complicate inference on how competition affects quality. The main differences between Cohen and Mazzeo's analysis and the present paper are: 1) our use of panel data to study the timing of quality improvements, and 2) our use of post-diffusion data to examine how firms benefited from their technology adoption strategies.[13]

The final related area of the literature concerns the introduction of new procedures or services in medical markets. Vogt [1999] and Schmidt-Dengler [2005] consider competition's role in the diffusion of MRI services to small medical markets. However, these papers do not investigate whether a new technology would become available earlier in a more competitive market.[14] Dafny [2004] considers the incentive for incumbent hospitals to deter entry by making a cost-reducing investment: a deliberate increase in a hospital's number of cardiac treatments to decrease marginal costs through learning-by-doing. Dafny's estimates support the argument (in

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[11] See Prescott and Visscher [1977], Schmalensee [1978], and Bonnano [1987] for examples.

[12] There is a growing literature on how firms choose the amount of *variety* they offer consumers. See Watson [2004] and references within for examples. We consider this area of research to be distinct from relevant portions of the product differentiation literature because consumers are described as valuing variety itself in a product menu. Consumers may hold preferences of this sort because of uncertainty or the desire to purchase a portfolio of products. Potential IVF (and ICSI) patients purchase a single treatment, and typically have ample information about their preferences and needs for ICSI when it is time to purchase treatment from a clinic.

[13] An additional minor difference is that each bank studied by Cohen and Mazzeo chooses a single product quality, while ART clinics choose whether and when to extend their product menu by offering ICSI, an additional high-quality service.

[14] Vogt conditions on market structure by examining MRI adoption in markets with exactly two hospitals (potential adopters). Schmidt-Dengler solves for equilibrium adoption decisions within the estimation of a structural empirical model based on Fudenberg-Tirole, so he is effectively constrained to find that additional competition leads to the earlier introduction of MRI into a market. Schmidt-Dengler's objective is to estimate the relative sizes of the business-stealing and preemption incentives in the Fudenberg-Tirole model.

Ellison and Ellison [2000]) that hospitals with a small but positive number of potential entrants are the most likely to inflate their number of treatments, but she also finds that this activity was apparently unsuccessful in foreclosing entry. Dranove *et al.* [1992] examine the importance of a "medical arms race" (MAR) among hospitals in the provision of specialized services. The possibility of a MAR, perhaps due to the preferences of physicians or insurance's effect on lowering consumers' price sensitivity, is a leading argument for welfare-reducing competition among hospitals.[15] While Dranove *et al*. find evidence that more competitive markets are associated with larger numbers of specialized services at hospitals, the magnitude of the MAR effect is economically small. Other research on new medical technology and services typically focuses on how institutional characteristics like insurance and hospital characteristics affect activity.[16]

An important difference between the papers on medical markets cited above and the present one is that previously studied medical markets may be strongly affected by institutional details such as insurance reimbursement practices and entry regulation. Infertility treatment clinics are unregulated in their entry and operation, and patients frequently pay for treatment out-of-pocket. Because of this, potential patients may have a stronger incentive to search for high quality and low prices than in medical services markets in which insurers pay for treatments.[17] This, in turn, may provide competitive ART clinics with stronger pressure to use cutting-edge technology. In general, the incentives in markets for patient-pay medical services are similar to those in other non-medical markets.[18] Additionally, if health care policy reforms result in additional choices by patients (perhaps through health care savings accounts), other markets for medical treatments may evolve to share some important characteristics with the ART market.

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[15] We do not study the welfare effects of ICSI diffusion in the present paper due to data limitations. However, we suspect that the likelihood of an inefficient MAR is lower in ART markets than in other medical service markets because patients pay out-of-pocket for treatment. Similarly, competitive pressure to adopt a new technology may reduce welfare in a model such as Fudenberg and Tirole [1985], but this result is typically obtained under an assumption of inelastic demand for the firms' products.

[16] For examples, see Baker [2001] on MRI technology, Baker and Phibbs [2002] on neonatal intensive care units, or Lee and Waldman [1985] on "small-ticket" technologies.

[17] Of course, insurers also have incentives to identify health care providers that offer high-quality treatment at low prices. However, an insurer's search across health care providers will not account for patient-specific match values in the same way the individual patient would.

[18] Examples of other health care services in which patients often pay the full expense of treatment include cosmetic surgery and LASIK eye surgery.

III. Background on ART Markets

III.A. ART, IVF, and ICSI

The U.S. market for IVF and other ART procedures has grown substantially in recent years. Between 1992 and 2001, the number of ART treatments increased from 38,000 to 108,000. Treatments in 2001 lead to the births of 40,700 children.[19] ART procedures are distinct from other infertility treatments in that ART entails handling both a woman's eggs and a man's sperm outside of the body.[20] IVF is the dominant form of ART, accounting for 77% of all treatments in 1992 and 99% in 2001.[21] During IVF eggs are fertilized in a laboratory. This procedure may be performed with greater precision via ICSI, in which a single sperm is injected into an egg. ICSI is of greatest help to couples with male-factor infertility, for whom sperm counts are low or sperm function is poor.[22] This is an important feature of ICSI procedures, since male-factor infertility is the reproductive problem least receptive to non-IVF treatments such as the use of ovulation drugs. Thus, we suspect that the invention of ICSI has improved conception chances for many couples who were not well-served by previously existing technologies.

The cost of adopting ICSI has two important components. First, the clinic must purchase specialized equipment – essentially a high-powered microscope plus delicate tools for inserting a sperm into an egg – for performing the procedure. The second cost component is expertise by the embryologist who performs ICSI. It is generally accepted within IVF markets that there is learning-by-doing in ICSI, so that additional ICSI procedures today will lower the marginal cost of successfully fertilizing an egg tomorrow. This implies that a clinic that performs more ICSI cycles can be viewed as making a greater commitment to improving the quality of treatment for patients who receive ICSI. Both ICSI adoption costs have the important characteristic that they are not (or cannot) be shared across IVF fertilization laboratories or medical institutions in

[19] The high frequency of twin and triplet births following IVF generates the difference between the success rate cited in the introduction (27%) and the relationship between the numbers of treatments and births.

[20] Other infertility treatments may include giving the woman drugs to stimulate egg production, or performing Intra-Uterine Insemination (IUI) which involves a doctor handling the sperm but not the eggs.

[21] In previous versions of this research we have studied how market characteristics contribute to the dominance of IVF over other forms of ART. We found that IVF grew more quickly in competitive markets, but the results for this comparison are not as clean as competition's effect on ICSI. This is because IVF was the only ART procedure in the early 1980s, and then a pair of competing technologies (GIFT and ZIFT) rose and fell in popularity during the late 1980s and early 1990s.

[22] A debated aspect of ICSI is whether it leads to a higher incidence of miscarriages or birth defects, since a doctor or embryologist selects the "successful" sperm rather than relying on natural selection.

general.[23] The physical capital must be stored and used at the IVF lab that offers ICSI to minimize the risk to the sperm, egg, and/or embryo. Additionally, the equipment is specific to ICSI and has little benefit to neighboring medical offices if an IVF clinic is located within a hospital. The human capital component of ICSI costs are similar in that we know of no (human) medical treatments outside of ART that would benefit from accumulated ICSI experience.[24]

III.B. Insurance mandates and ICSI adoption

An additional important characteristic of ART markets is the presence of state-level regulations regarding how insurance providers must cover or offer coverage for infertility treatments. During 1992-2001, eight states with clinics had mandates that required insurers to cover ART treatments. These can be relatively strong policies that, in some cases, significantly shift the number of treated couples and the decisions made during treatment. The states with the strongest mandates – Massachusetts, Rhode Island, and Illinois – are identified as "universal" mandate states in the analysis below. Coverage mandates that exclude some firms and insurers are referred to as "restricted" below; states with these mandates are Arkansas, Hawaii, Maryland, Ohio, and West Virginia. In related research (Hamilton and McManus [2005]), we provide a detailed analysis of how treatment varies across clinics in states with universal and restricted coverage mandates.

The demand effects of these coverage mandates may shift the return from offering ICSI, so we control for these regulations in the analysis below. Some states' mandates include ICSI as covered procedure. Even where ICSI is not covered, the additional demand for IVF may increase the demand for ICSI, making clinics more likely to offer the new technology. Alternatively, insurance mandates may increase the average price sensitivity of IVF patients because lower-income people are more likely to take treatment, and this could reduce clinics' profit from introducing ICSI.

In addition to the states listed above, an additional four states had weaker mandates that required insurers to offer coverage for ART treatments. While these "mandates to offer" may have a smaller effect on the number of treatments, we note that in 1990 California enacted a mandate that explicitly excluded IVF and favored the ART procedure Gamete Intra-Fallopian

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[23] Some clinics share laboratories, and therefore a pair of clinics may each offer ICSI following the diffusion of ICSI technology to a single lab. However, the number of clinics in this situation is small.
[24] Many modern infertility treatments were developed as techniques for animal husbandry.

Transfer (GIFT), which cannot be augmented with ICSI. We suspect that this regulation reduced the benefit to California clinics from performing IVF, which would have slowed the diffusion of ICSI in the state. We test for this effect in Section V below.

IV. Data

Our data on individual ART clinics cover the period 1989-2001, and most of our analysis focuses on 1992-2001, after the introduction of ICSI.[25] For each of the years within this period, we know the number of treatments administered by a clinic, the clinic's use of various ART technologies, and the percentage of treatments that yielded births. The data require us to identify the beginning of a treatment as the stage in which a woman's eggs are retrieved.[26] Further limitations of the data are that we do not observe the count of the number of patients that receive an ART procedure at a clinic, and we do not know the prices charged for IVF and ICSI. Each year's count of treatments at a clinic is very likely to include some patients who attempt ART multiple times. There were 544 unique clinics that operated between 1992 and 2001; the number of operating clinics increased from 233 to 381 during this period. The average size of a clinic grew from 131.3 retrievals per year to 174.2 retrievals.

ICSI availability grew most rapidly between 1992 and 1997, when the proportion of clinics offering the procedure grew from 22% to 86%. Since 1998, the fraction of clinics that offer ICSI has remained around 90%. While most clinics eventually offered ICSI, its use as a percentage of all treatments has not grown as quickly. ICSI use doubled each year between 1992 and 1996 until it reached 25%, and then grew at a rate of about 5 percentage points each year from 1996-2001 to reach 48% of all treatments. Clinics that have adopted ICSI generally do not specialize in using the technology during treatment; during 1998-2001 a clinic at the 75th percentile of ICSI frequency used the procedure only 55% of the time. The incomplete diffusion of ICSI at the clinic and patient levels is evidence that ICSI is a differentiated product in the ART market rather than simply a cost-reducing technology that should be adopted eventually by all clinics.

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[25] The data from 1989-1994 are from the Society for Assisted Reproductive Technology. The 1995-2001 data are from the Centers for Disease Control and Prevention.

[26] A more general definition of treatment would begin to track a woman when she begins to receive drugs to stimulate egg production.

As we begin to investigate whether market structure affects technology adoption, we are also interested in whether different types of clinics pursue different technology strategies. In Table 1 we present conditional means on ICSI availability and frequency for a variety of clinic characteristics during the period 1996-2001. The availability and frequency of ICSI do not vary substantially by clinic age or hospital/university affiliation, but there is a notable difference in the availability of ICSI by clinic size. Virtually all clinics with a number of retrievals in the upper quartile (nationally) offer ICSI. There are two interpretations of this regularity. First, large clinics can spread the fixed costs of ICSI across more patients. Second, clinics in competitive markets tend to be larger than monopoly clinics, because additional competition shifts both clinic size and ICSI adoption.[27]

Ultimately, issues of switching among technologies are important only to the extent that these changes affect the productivity of infertility treatment. We examine how clinic-level birthrates vary with the overall use of ICSI in a clinic and report summary statistics in Table 2.[28] We divide the data into three multi-year periods (1992-95, 1996-98, and 1999-2001) and find that clinics with ICSI had relatively high birth rates during each period. The difference in success rates between clinics with and without ICSI grows as the technology's use becomes more common at clinics that offer it. We also report that the clinics that performed ICSI more frequently in their respective markets had higher birth rates during the two later periods, 1996-98 and 1999-2001. In general, these statistics suggest that transitions across treatment technologies were beneficial in shifting clinics' productivity or quality of care.

IV.A. Market assumptions and data

In order to analyze how market structure affects clinic strategies, we need to define the relevant markets. We assume that the boundaries of Metropolitan Statistical Areas (MSAs) define local markets for infertility treatment. When a group of MSAs are geographically clustered and the U.S. Census Bureau identifies the MSAs as a Consolidated Statistical Area

[27] The effect of entry on equilibrium firm size is discussed in Bresnahan and Reiss [1991]. We exclude clinic size from the analysis below so that we can capture the full effect of competition on ICSI diffusion. However, when we estimate clinic-level models of ICSI adoption with lagged size as an additional control variable, the results are extremely similar to those reported below.

[28] We do not have data on how treatment success varies within a clinic conditional on the use of ICSI.

(CSA), we use this larger geographic area as the market.[29] Our rationale for this market definition is that ART patients require repeated meetings with their doctors during treatment, so travel to a different metro area is very likely to be time-consuming and expensive.[30]

We present the characteristics of markets with zero, one, and more than one clinic in Table 3.[31] ART patients are often women who delayed childbearing in order to receive graduate degrees and/or pursue careers during their most fertile years. Consequently, we are not surprised to find that markets with clinics tend to have large populations of women between ages 25-44, high income levels, and many women with post-secondary education. The number of markets with ART clinics grew from 91 in 1992 to 107 in 2001, with the clinics initially operating in the markets with the most favorable demand characteristics and expanding downward; the per-clinic population of potential patients falls during the sample period.

IV.B. Preliminary analysis of market structure and technology

We measure market structure with a binary variable, *COMP*, which is equal to 1 when a market has two or more firms, and is equal to 0 if the market is a monopoly. During 1992-2001 the fraction of markets that were monopolies fell from 53% to 43%. Figures 1 and 2 display the diffusion pattern of ICSI across monopoly and non-monopoly markets. Figure 1 shows that by 1996 every competitive market had at least one firm with ICSI technology, while ICSI was still unavailable in some monopoly markets in 2001. The pattern is qualitatively similar but not as dramatic for clinic-level comparisons of ICSI availability, shown in Figure 2. The average competitive clinic was more likely to offer ICSI than a monopoly clinic in each year since ICSI's invention.

While Figures 1 and 2 suggest that competitive IVF clinics feel greater pressure to offer a new technology than monopoly clinics, it is clear that more careful analysis is necessary to evaluate the question of whether exogenously adding a clinic to a monopoly market would increase or decrease the speed of ICSI diffusion. This is not just a matter of including controls for observable market characteristics in econometric models that describe how the probability of

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[29] For example, the Washington D.C.–Baltimore area includes multiple MSAs that are grouped together as one CSA because of the frequent activity that occurs across MSA borders.

[30] In the medical literature, Steiner *et al*. [2005] also define the MSA as the market for IVF services.

[31] The data on population, income, and education all come from the U.S. Census Bureau. In addition to the demographic variables on Table 3, in our empirical models we also use data on the percentage of Catholics in each market. We include this variable because Catholicism is the only major religion in the U.S. which counsels its adherents against all fertility treatments. The data on religious affiliation are from the Glenmary Research Center.

introducing ICSI varies with market structure. There may be important unobserved factors that shift both overall demand for IVF (and therefore the number of firms) in a market and the return from offering ICSI. We estimate "pre-program" regressions (Heckman and Hotz [1989]) to investigate whether markets that were among the first with ICSI also differed in market structure or had a high level of demand for IVF in general. We first estimate a probit regression of whether a market was competitive (2+ clinics in market) or monopolized in 1991, prior to the commercial introduction of ICSI. We specify market structure to be a function of a set of contemporary control variables plus an indicator of whether ICSI was introduced into the market between 1992 and 1994. The first column of Table 4 shows that markets in which ICSI was introduced earlier were less likely to be monopolies in 1991, although the statistical significance of this result is not strong ($p = 0.202$). Since future ICSI diffusion cannot actually affect market structure, this result suggests that there are unobserved market-level factors correlated with both overall demand for IVF and the propensity to adopt new technology. The second column of Table 4 presents estimates from a similar regression using the (log) number of IVF treatments performed in the market in 1991 as the dependent variable. This provides additional evidence that markets with early adoption of ICSI also had greater demand for IVF prior to the introduction of ICSI. Together, these results on market structure and the number of treatments confirm our intuition that unobserved market characteristics may affect both demand for IVF and ICSI diffusion, and that we need to account for the potential endogeneity of competition in our models of technology diffusion below.

V. Market Structure and ICSI Diffusion

V.A. Market-level estimates

Many of the predictions from theory discussed in Section II concern market-level phenomena. Analyses of the adoption of cost-reducing technologies consider whether the first adopter in a competitive market starts using a new technology before a monopolist. Similarly, studies of product differentiation may examine whether the overall menu of products offered by a collection of competing firms is broader than that of a single multi-product monopolist. To evaluate these issues of market-level characteristics, we begin by estimating the following model:

$$y^*_{mt} = \alpha_1 COMP_{mt} + X_{1mt}\beta_1 + \varepsilon_{mt}\,, \qquad (1)$$

where y^*_{mt} is the latent, continuous value in market *m* from <u>some</u> clinic adopting ICSI. When $y^*_{mt} > 0$, we observe $y_{mt} = 1$, indicating that at least one clinic in the market offered ICSI by the end of year *t*. When $y^*_{mt} < 0$, no clinic in the market offers ICSI by the end of *t*. The vector X_1 is a set of control variables, and the error term ε contains unobserved market-level demand and cost characteristics. We observe in the data that clinics always continue to use ICSI for some patients after it is initially adopted. Consequently, we use equation (1) to estimate the discrete hazard probability of adoption, $\Pr(y^*_{mt} > 0 | y^*_{mt-1} < 0)$. This is the probability that ICSI is offered in market *m* in year *t*, conditional upon ICSI not being offered in *t*–1, for the years 1992-1998. Recall that ICSI was introduced in 1992 so no firm used ICSI in 1991, while ICSI was available in almost all markets by 1999. If business-stealing and preemption incentives dominate IVF treatment markets (as in the technology adoption model of Fudenberg and Tirole [1985]), then we will find α_1 is positive. On the other hand, if entry foreclosure or monopoly price discrimination strategies are central, we will find that α_1 is negative.

Equation (1) also has a natural policy interpretation. Suppose we take the point of view of a couple who is shopping for treatment options. If the couple has specific treatment needs (perhaps due to male factor infertility), then they may believe that it is important that some clinic in their home market offers ICSI. Multiple clinics offering ICSI may lead to a reduction of prices, but these savings may be second-order relative to the availability of ICSI.

As we noted above, unobserved market-level demand and cost characteristics captured in ε may be correlated with the level of competition in the market. To account for the potential endogeneity of *COMP* in our analysis of ICSI diffusion, we identify market-level cost-shifting variables that may influence the market structure within an MSA, but which do not directly affect the ICSI adoption decision of a clinic. First, since IVF clinics are often affiliated with hospitals with which they may share fixed costs, markets with more hospitals are likely to have more clinics. Recall from Section III.A that ICSI equipment and expertise is largely confined to the IVF clinic, so that the cost of adopting ICSI will not be shared with the hospital. Consequently, the number of hospitals in the market should affect adoption only through market structure. Another cost-shifter is the number of research MDs in a market. ART clinics require staffs that are familiar with medical and laboratory environments, and markets with a high number of research MDs are likely to have a thicker labor market for potential ART clinic employees.

Denoting the vector of cost-shifting variables by Z_{mt}, we specify the latent measure of clinic competition in market *m* in year *t*, $COMP^*_{mt}$, as

$$COMP^*_{mt} = X_{1mt}\beta_2 + Z_{mt}\gamma_2 + u_{mt}. \qquad (2)$$

We interpret this equation as a reduced-form model of how equilibrium market structure is determined by exogenous demand and cost factors. We use the model to estimate the probability that there are at least 2 clinics in market *m* in year *t* (i.e., that $COMP_{mt} = 1$). In the empirical analysis below we refer to estimation of equation (1) alone as "Probit," and joint estimation of equations (1) and (2) as "BVP" (for bivariate probit). The BVP specification accounts for the potential endogeneity of *COMP* in equation (1) by allowing for non-zero correlation between ε and *u*.[32]

We present the discrete hazard estimates of market-level ICSI diffusion for the period 1992-1998 in Table 5, where the table entries are the probability derivatives associated with a one unit change in the associated variable. The table includes two notable results. First, ICSI technology was adopted more quickly (by at least one clinic) in competitive markets than in monopolized markets. This is true even after accounting for the potential endogeneity of the number of clinics in the market. This result is consistent with the theoretical predictions of Fudenberg and Tirole [1985] on sub game-perfect technology adoption strategies. From the perspective of product differentiation, the result supports the idea that competitive firms' incentives to vertically differentiate and soften price competition are stronger than a monopolist's potential profits from price discrimination. Second, regulatory constraints have played an important role in the diffusion of ICSI in California markets. ICSI diffusion in California occurred at a significantly slower pace than in other markets. This is consistent with the view that California clinics had less incentive to adopt ICSI, since the state's regulations

[32] There is some discussion in the literature on the appropriate method of estimating limited dependent variable models with dummy endogenous variables. Angrist [1991] expresses concern that if the joint normality assumption is violated, the resulting BVP estimates of the treatment effect of competition on diffusion may be biased. He advocates estimating a simultaneous equation linear probability model (see Heckman and MaCurdy [1985]). However, recent Monte Carlo evidence in Bhattacharya *et al*. [2005] suggests that BVP may be preferable to the linear probability model even under departures from normality. We estimated the specifications in Tables 5 and 6 using linear probability models and found similar results to those presented in the tables. These results are available from the authors upon request.

favored an ART procedure (GIFT) with which ICSI cannot be used. This finding is particularly important for patients because GIFT is a more invasive, less effective technology when compared to IVF alone and especially IVF with ICSI.

When we account for the potential endogeneity of market structure, we observe an increase in the magnitude of competition's effect on ICSI diffusion or use. The direction of change results from a negative correlation between the error term in (1) and *COMP* (we estimated corr(ε, u) = -0.363 in the BVP model). This may occur because incumbents' use of ICSI effectively forecloses entry by new competitors. A firm's benefit from adopting ICSI is greater if it has a high idiosyncratic return from the technology, and this clinic-level effect is correlated with the market-level error term in (1). However, if an incumbent firm's adoption decision reduces the benefit from entry for a new potential firm, then there will be negative correlation between u and ε. The direction of change in parameter estimates in Table 5 is the opposite of what would occur if unobserved demand factors increased both the benefits of entry and the return from offering ICSI. In this case, the correlation between *COMP* and ε would have been positive.

V.B. Clinic-level adoption decisions

While the results on Table 5 provide evidence that markets with multiple clinics were the first to have a clinic with ICSI, these results may be due to factors that are unrelated to strategic incentives in technology adoption. In particular, if it is the case that each clinic has an independent shock to its cost of adopting ICSI, then markets with more clinics will have a higher probability of at least one clinic offering the technology simply because more clinics have drawn from the distribution of costs. Alternatively, it may be the case that clinics' characteristics are different in competitive markets than monopoly ones (for example, perhaps they are more likely to be associated with a university), and these differences across clinics drive differences in ICSI diffusion rates.

To address these concerns, we estimate a descriptive model of an individual clinic's likelihood of adopting ICSI. Continuing with the notation of equation (1), let y^*_{imt} be clinic i's latent, continuous benefit from adopting ICSI. We specify that this benefit can be affected by market characteristics (X_{mt}, $COMP_{mt}$) and i's own characteristics (W_{it}). The variables in W include indicators of whether i is associated with a hospital or university, and whether the clinic was founded after the introduction of ICSI (i.e., founded after 1991). These factors are combined in the following model:

$$y^*_{imt} = \alpha_3 COMP_{mt} + X_{1mt}\beta_3 + W_{it}\gamma_3 + \varepsilon_{imt} \,. \qquad (3)$$

This model is descriptive (rather than structural) because it does not account for how clinic *i*'s technology choices are affected by the ICSI decisions of other clinics in the market (note that $COMP_{mt}$ refers to the number of clinics in the market, <u>not</u> the number of clinics offering ICSI).[33] Instead, we prefer to interpret this model as a description of the behavior of an average clinic in a market, conditional on the data in *COMP*, X_1, and *W*. If we find that *COMP* has a positive and significant effect on y^*_{imt} in equation (3), then we conclude that the positive α in our market-level analysis is due to shifted behavior under competition, and not just clinic characteristics or randomness in cost shocks. As above, we are concerned that *COMP* is correlated with ε_{imt}, so we estimate (3) jointly with equation (2) in a bivariate probit (BVP) model. Since clinic adoptions of ICSI occurred throughout the sample period of 1992-2001, we use the full panel in estimating the discrete hazard of ICSI adoption specified by (3).[34]

The estimates of the clinic-level models in Table 6 exhibit three notable results. First and most importantly, clinics in markets with more than one firm adopt ICSI more quickly than monopoly clinics, particularly when the possible endogeneity of market structure is accounted for in the estimation procedure.[35] Second, the discrete hazard estimates suggest that clinics founded after the invention of ICSI tend to either enter the market offering ICSI or adopt it soon after entry. This supports our view that the technology adoption model of Fudenberg and Tirole [1985], in which adoption decisions may be made at any time, is more closely related to the present application than Reinganum [1981]. ICSI may be a source of differentiation for new entrants. Third, insurance regulations do not appear to impact the adoption hazard. Given the

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[33] An individual clinic's benefit from adopting ICSI will depend on the presence and technology decisions of other clinics in the market. Therefore, a full clinic-level model of decisions to adopt ICSI should include a specification of the game played among competing clinics in entry and technology decisions. The game may be best specified as a dynamic one, and the econometrician would need to address the issue of simultaneity of technology decisions among clinics in estimating a behavioral model of clinics' technology choices. It is outside of the scope of this paper to specify and estimate such a model. Indeed, we are concerned that applying the equilibrium conditions of a technology game to the estimation procedure would prevent us from actually testing which predictions of theory are realized in clinics' ICSI choices.

[34] Some clinics that are founded after 1991 offer ICSI immediately upon market entry. We include these observations in the sample and set $y_{imt} = 1$ for them.

[35] This repeats the pattern seen at the market level that estimates which account for competition's potential endogeneity are larger in magnitude than estimates obtained under an assumption of exogenous competition.

market-level results above, it is somewhat surprising that individual clinics in California do not appear to lag clinics in other states in their ICSI decisions. However, this reflects the time frame used for the estimates in Table 6. By the late 1990s GIFT was widely thought to be inferior to IVF, and so the incentives provided by California law for GIFT had little "bite" and did not influence the ICSI adoption decisions of clinics by the year 2000. When we limit the clinic sample to the years 1992-1997, we find that California clinics are 7.3% less likely to adopt ICSI in a given year during that period.

VI. Was Early Technology Adoption Beneficial to Clinics?

In the previous section we considered which markets were most likely to include a clinic offering ICSI soon after its invention. We now consider *why* a clinic would choose to be among the early adopters of ICSI. Our data provide an interesting opportunity to carry out this analysis, since we observe several years of clinic performance following the most active period of ICSI adoption. This is unusual among empirical studies of technology diffusion and new products. Dynamic studies of technology adoption typically focus exclusively on the period of diffusion activity, perhaps because of data limitations.[36] Similarly, empirical analyses of product differentiation are usually static and take market structure to be independent of firms' product menus, so there is little opportunity to study the benefits of when to extend the menu or the strategic introduction of new products to foreclose entry.[37]

It would be ideal to examine the benefits of ICSI adoption through a study of clinics' profits. Unfortunately, data on profits are not available, so we consider several proxies instead. We first study the impact of early adoption on clinic demand, as measured by the number of IVF treatments performed, and market share during the years 1996-2001. We choose this period because by this time ICSI had diffused to all markets with at least two clinics. We then

[36] For examples of studies which investigate the timing of technology adoption by are limited to adoption activity itself, see Hannan and McDowell [1984a, 1984b], Genesove [1999], or Schmidt-Dengler [2005]. To our knowledge, the only exception is Dafny [2004], who finds that the cost-reducing investment she studies was not successful in preventing rivals' entry.

[37] For example, in Petrin's [2002] study of the benefits from introducing the minivan, this new product effectively appears exogenously in U.S. auto markets. Cohen and Mazzeo [2005] estimate a function that describes banks' equilibrium choices of the number of branches (a quality measure), but their cross-sectional data does not permit an analysis of how branching activity affects bank performance or profit.

investigate how accumulated years of ICSI experience affects the ability of a monopoly clinic to delay the entry of rivals.[38]

VI.A. The impact of early adoption on clinic size and market share

To capture the effect of ICSI adoption on clinic performance, we adopt a "differences in differences" approach that takes advantage of data on clinic performance during 1989-1991, prior to the invention of ICSI. This pre-ICSI data allows us to account for unobserved clinic and market-level fixed effects that are potentially correlated with both ICSI adoption and performance. For this portion of the analysis, we designate as "early adopters" clinics that began offering ICSI between 1992 and 1995. For these clinics, we set the indicator variable $EARLY_{imt}$ equal to 1, while for all other clinics the indicator value is zero. We examine both the initial impact of early adoption on clinic success and whether the impact persists by estimating regressions of the form:

$$y_{imt} = \alpha_4 COMP_{mt} + X_{2mt}\beta_4 + W_{it}\gamma_4 + \sum_{s=96}^{01} \delta_s EARLY_{imt} * 1\{t = s\} + \theta_{im} + \eta_{imt}, \quad t = 1989, 1990, 1991, 1996, \ldots, 2001. \qquad (4)$$

The variable y is a measure of clinic success (number of treatments or log market share), and *COMP*, *X*, and *W* are as defined for equation (3), with the exception that X_2 contains a full set of year dummies. The indicator function 1{.} = 1 if the expression in braces is true. The δ_s coefficients indicate whether early-adopting clinics saw more patients or increased market share compared to late- and non-adopters between 1996 and 2001 (i.e., $\delta_s > 0$), and whether this advantage erodes as more clinics adopt ICSI (i.e., $\delta_{96} > \delta_{01}$). The fixed effect θ_{im} in equation (4) accounts for unobserved clinic and market characteristics that may be correlated with the firm's adoption decision and the level of competition in the market.

The results in column (1) of Table 7 indicate that early adoption of ICSI was associated with a substantial increase in the number of IVF treatments performed. This is evidence consistent with the view that early adoption of ICSI may have been propelled by the appeal of attracting more patients to a clinic. The benefits of early adoption in terms of the number of

[38] With richer data, we might investigate how a clinic's probability of exit is affected by its ICSI history. We observe 65 clinics exit during the period 1995-2000, but this is only 3% of the clinic-year combinations at which a clinic might exit its market.

patients appear to persist over time, so that early adopters continue to treat approximately 100 more patients in 2001.

The estimates in column (1) constrain the impact of early adoption to be the same for clinics operating in competitive and monopoly markets. However our finding that ICSI diffused first to competitive markets suggests that the values of δ may differ by market structure. In a monopoly market, an early adopter of ICSI may experience an influx of patients because couples with male factor infertility or other problems have a greater likelihood of a birth and are more likely to attempt IVF. This is true in a competitive market as well, but early-adopting firms may additionally attract patients away from later-adopting rivals. To contrast the patterns for different market structures, we re-estimate equation (4) separately for clinics that operated in a competitive market and clinics that were monopolies. Comparison of columns (2) and (3) of Table 7 show that early adopters in competitive markets experienced substantially larger increases in treatment cycles between 1996 and 2001 than did monopoly clinics. These findings are consistent with the view that early adoption was more profitable for clinics operating in competitive markets, providing them with a stronger incentive to offer ICSI.

We next examine how the increases in the number of patients treated by early adopters of ICSI translated into market share advantages. While this analysis is similar to that in columns (1) and (2), the results for market share have a clear relationship to the business-stealing incentives discussed in the theory literature. In order to consider market shares in a sensible way, we limit our analysis to firms operating in non-monopoly markets. In column (4) we pool together firms operating in markets that were competitive throughout the sample period with firms operating in markets that switched from monopoly to non-monopoly; in column (5) we restrict the sample to markets that were competitive throughout the sample period. The estimates show that early adoption of ICSI yielded a substantial growth in market share in 1996. Over time, however, the market share advantage associated with early adoption eroded as other clinics adopted ICSI. This result is possible along with the relatively stable values of δ in column (2) because the average clinic treated many more patients in 2001 than in 1996.

VI.B. Early adoption and entry deterrence

In addition to our measures of clinic performance in size and market share, we use our data to evaluate whether early-adopting monopoly clinics were actually successful in delaying the entry of competitors. There were 45 markets that were monopolized in 1991, and by 2001 23 remained as monopolies. For each year between 1992 and 2001 we estimate the conditional probability that a market became competitive during *t*, given that it was a monopoly in t–1. We specify the discrete hazard of a transition from monopoly to competitive market structure as a function of the incumbent clinic's characteristics, including a variable measuring the clinic's "years since adopting" ICSI, denoted YSA_{mt}.[39] For years prior to adoption, $YSA_{mt} = 0$. Market-level variables, including demographic and regulatory characteristics, also may affect the probability of transition. Let y^* be a latent, continuous index of the appeal of entry into market *m* during year *t* for a new clinic. Entry occurs if $y^* > 0$, where

$$y^*_{mt} = \alpha_5 YSA_{mt} + X_{1mt}\beta_5 + W_{mt}\gamma_5 + \varsigma_{mt}, \quad t = 1992,\ldots,2001. \tag{5}$$

As above, the vectors X_1 and *W* are market and clinic characteristics, respectively. The variable subscripts in equation (5) are given at the market-period level because y^* is a market-level variable and given the sample (of monopoly markets) it is harmless to interchange *i* and *m*. Unobserved shocks to the value of entering a market, ζ, are clustered within markets over time.

The estimates of the discrete hazard probability $\Pr(y^*_{mt} > 0 | \, y^*_{mt\text{-}1} < 0)$ utilizing equation (5) are presented in Table 8.[40] We find that for each additional year of ICSI experience by a monopolist, the probability of entry into a market falls by 2.5%.[41] We note that this is the only clinic characteristic that has a statistically significant effect on the entry probability of a rival firm. It is apparently a clinic's ICSI experience – and not the reputation effects of being old in general or associated with a hospital or university – that diminishes the probability of entry into a market. To our knowledge, this evidence of entry preemption is novel to the literature on technology adoption and product differentiation.[42]

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[39] An advantage of using *YSA* rather than the variable *EARLY* to measure ICSI experience is that the former allows us to use data from years prior to 1996. We also estimated a similar model using *EARLY* instead of *YSA*, and we found qualitatively similar results. The main difference is that the coefficient on *EARLY* is significant at the 10% level while our results using *YSA* are significant at 5%.

[40] We also estimated this model with a control for clinic size during (t–1), and the results are virtually unchanged.

[41] We estimate equation (5) under the assumption that *YSA* is orthogonal to ζ. If this was not the case, the correlation between *YSA* and ζ would probably be positive. (Unobserved demand shocks may increase the incumbent's return from ICSI and the appeal of entry.) However, positive correlation of *YSA* and ζ would result in an upward-biased estimate of α, which means that the effect reported on Table 8 is likely to be a lower bound on the magnitude of delay.

[42] Mazzeo's [2002] model of endogenous quality choice by motels is similar in that firms choose their product characteristics in anticipation of rivals' choices. However, Mazzeo finds that altering the timing of the entry and quality game to allow for Stackelberg leadership does not yield different results than a simultaneous-move game.

Overall, the results of this section suggest that early adoption of ICSI affects both market structure itself and performance conditional on structure. Early-adopting monopoly clinics have a greater chance of deterring entry, while clinics in competitive markets experience increased demand and market share relative to their rivals. However, as we would expect, these advantages in market share dissipate over time as rival firms adopt ICSI as well.

VII. Conclusion

During the last twenty years there have been several advances in infertility treatment that have substantially increased treatment success rates. The timing of these advances has been fortunate, since there is an increasing demand for treatment due to the changing life-cycle choices of women. Women are marrying later, staying in school longer, and devoting more time to professional careers.[43] These choices lead women to delay childbearing, but as all people age their natural fertility declines. Treatments such as IVF can help reverse or slow this decline in conception chances, and give women better opportunities time the births of their children around their career and schooling goals. Path breaking improvements to ART technology, such as the ICSI procedure studied in this paper, allow these lifecycle decisions to be made more precisely and less expensively.

We find that competitive markets were more likely to include a clinic that offered ICSI than monopoly markets. Our BVP results imply that the addition of a second firm to a monopoly market increases by 29% the probability that ICSI diffuses to that market in a given year. This is supported by the clinic-level results in Table 6, which imply that an increase in competition is associated with a 19% increase that an individual clinic will begin offering ICSI. This extension of the menu of treatment services may be especially helpful to potential patients with male-factor infertility, whose medical condition is particularly difficult to treat with less advanced technologies. Of course, a high level of competition does not simply increase the chance that ICSI is available, but it is also likely to lower the overall price of IVF and further expand treatment opportunities in a market.[44]

Our analysis also confirms that clinics which were among the earliest adopters of ICSI received measurable benefits from their choices. The finding that ICSI diffused first to

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[43] See Spraggins [2000].

[44] See Hamilton and McManus [2005] for estimates of the significant increase in treatment associated with a switch from monopoly to non-monopoly market structure.

competitive markets is supported by our observation that early-adopting competitive clinics experienced a significant increase in their size and market share relative to late- or non-adopters, while early-adopting monopoly clinics did not grow significantly following the introduction of ICSI. However, monopoly clinics that offered ICSI relatively early were less likely to observe entry into their markets than monopolists will less ICSI experience. This outcome may also explain why early-adopting monopolists had no significant increase in size relative to late-adopters; firms in the latter group were forced to increase their number of treatments following entry because competition depressed profit margins.

In considering which factors may have influenced activity in infertility treatment markets, we have drawn on intuition from two areas of industrial organization theory: technology adoption and product differentiation. An important feature of the literature on when firms adopt a cost-reducing technology is that it illustrates how changing a crucial assumption about the timing of moves in a dynamic game can alter the game's outcome. Our results support the results of Fudenberg and Tirole [1985], which show that when firms can adopt a new technology at any moment the technology will diffuse first to a competitive market. This is contrasted with Reinganum's [1981] model, in which firms make once-and-for-all commitments to adoption timing, and there is no opportunity for firms to gain an advantage on their competitors through preemption. However, it is insufficient to look only at the literature on cost-reducing technologies. Our data show that ICSI diffused incompletely in U.S. markets, which suggests that this technology should also be described as a new, differentiated product rather than a production improvement that all clinics should eventually adopt. Given this, we look to the literature on differentiated products to understand whether its predictions will complicate inference on technology adoption dynamics in IVF markets. We note that there are opposing differentiation and discrimination incentives that may speed or delay the diffusion of ICSI to competitive markets.[45] Our finding that ICSI diffused first to competitive markets supports the view that monopoly price discrimination opportunities, if they existed, were not sufficient to dominate the total effect of firms' desire to soften price competition through differentiation or capture the market share of their rivals.

Finally, in both areas of the literature we find arguments that a firm with market power may accelerate its adoption of a new technology or the introduction of a new product to prevent

[45] These factors are relevant regardless of whether open-loop or closed-loop dynamic strategies apply.

rival firms from entering its market. This may influence how ICSI diffusion varied with market structure, since these incentives are suggested to have a greater effect on monopolies than competitive firms. Additionally, the possibility of foreclosure strategies create an empirical challenge, since this implies that IVF market structure is determined endogenously with clinics' ICSI choices. Despite our evidence that foreclosure incentives do not lead to faster diffusion in monopoly markets, the results in Section VI.B show that this sort of activity is relevant to the IVF market and could benefit incumbent firms.

There are several areas for future research that could provide beneficial extensions to the present paper. First, there are issues related to individual clinics' strategies regarding entry, exit, and technology. In particular, it would be interesting to learn how one clinic's choice to offer ICSI affects another clinics' likelihood of introducing the technology. This could lead to inference on whether clinics have a strong incentive to differentiate themselves and soften competition, or alternatively whether there is pressure to keep pace with the product offerings of a competitor (as in a medical arms race). An additional benefit of a study of individual firms' strategies is a more direct calculation of the profit from various actions, which would extend the analysis we offer in Section VI.B. A second area for additional study is the welfare benefits of new technologies in infertility treatment markets. With additional data on IVF and ICSI prices and treatment outcomes, it could be possible to calculate the welfare impact of ICSI's invention. Calculations of this sort would be useful in evaluating the benefits and costs of public policies to stimulate competition or even encourage particular technologies, such as the policy adopted in California.

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Table 1
Clinic Technology and Characteristics, 1996-2001

	All Clinics	Clinic Start pre-1992	Clinic Start 1992-95	Clinic Start 1996-2001	Hospital or University Affiliation	Size in Upper Quartile
Offer ICSI (%)	87.0	91.4	89.1	80.3	89.6	97.7
ICSI Frequency (%) If Available	40.3	39.0	39.7	42.6	39.5	43.5
N	2274	1045	405	824	1225	573

Table 2
Birth Rates by Clinic Technology Status

	1992-95	1996-98	1999-2001
Offer ICSI			
Yes	20.3	26.2	29.4
No	19.7	21.6	25.3
ICSI %			
Above market median	19.4	26.6	29.3
Below market median	21.0	24.1	28.7

"ICSI %" is calculated for competitive markets only, in which a clinic can be evaluated relative to the market median ICSI frequency. "Offer ICSI" calculated for all markets.

Table 3
Characteristics of Markets with and without Clinics

	1992			2001		
Number of Clinics	0	1	2+	0	1	2+
Population, women age 25-44	32,863	111,873	535,971	30,579	83,686	420,829
Income (2001 dollars)	21,323	23,710	26,000	24,891	28,650	30,701
Women age 16+, % in labor force	54.6	59.9	58.6	52.9	60.2	59.2
Women age 25+,						
% with Bachelor's Degree	11.4	14.5	14.9	12.8	16.3	17.1
% with Graduate Degree	6.2	8.3	8.1	7.1	9.4	9.5
N	230	45	43	211	44	63

Table 4
ART Markets before ICSI, 1991

Dependent Variable	2+ Clinics in Market in 1991	Log of Treatments in Market in 1991
Estimation Method	Probit	OLS
ICSI present during 1992-1994	0.216 (1.27)	0.441 (2.08)
Competition	-	0.549 (2.70)
N	83	

Table entries in column (1) are marginal probabilities. t-statistics are in parentheses. We include the following controls in our models: Population of women age 25-44, educational achievement of women, average household size, percent Catholic, median income, and percentage of women over age 16 in the labor force.

Table 5
Discrete Hazard Estimates of Market-Level ICSI Diffusion

Dependent variable	Does ICSI become available in the market in year *t*?	
Years	1992-1998	
Method	Probit	BVP
Competition	0.106 (1.68)	0.292 (1.87)
Regulatory regime		
Universal mandate	0.139 (0.99)	0.201 (1.43)
Restricted mandate	0.059 (0.62)	0.076 (0.71)
California	-0.315 (-3.24)	-0.300 (-2.91)
N	94 Markets	

Table entries are marginal probabilities (treatment effects). t-statistics are in parentheses. Standard errors account for clustering of errors at the market level. We include the following controls in our models: Population of women age 25-44, educational achievement of women, average household size, percent Catholic, median income, percentage of women over age 16 in the labor force, and a time trend.

Table 6
Discrete Hazard Estimates of Clinic-Level ICSI Adoption

Dependent variable	Does the clinic adopt ICSI in year *t*?	
Years	1992-2001	
Method	Probit	BVP
Competition	0.066 (1.59)	0.189 (3.68)
Clinic characteristics		
Hospital	0.049 (1.38)	0.048 (1.34)
University	0.018 (0.42)	0.027 (0.62)
Founded after 1991	0.162 (3.89)	0.162 (3.83)
Regulatory regime		
Universal mandate	0.020 (0.29)	0.020 (0.28)
Restricted mandate	-0.047 (-0.61)	-0.067 (-0.80)
California	0.021 (0.39)	0.021 (0.40)
N	530 Clinics	

Table entries are marginal probabilities (treatment effects). t-statistics are in parentheses. Standard errors account for clustering at the clinic level. We include the following controls in our regression models: Population of women age 25-44, educational achievement of women, average household size, percent Catholic, median income, percentage of women over age 16 in the labor force, and a time trend.

Table 7
Difference-in-Difference Estimates of the Benefits of Early ICSI Adoption

Dependent variable	Number of Treatments			Log of Market Share	
Sample	All Clinics	$COMP_{mt}$ = 1	$COMP_{mt}$ = 0	$COMP_{mt}$ = 1	Competitive Clinics, 1989-2001
Specification	(1)	(2)	(3)	(4)	(5)
δ_{96}	90.248 (3.95)	118.030 (3.83)	27.606 (1.06)	0.485 (2.15)	0.556 (2.06)
δ_{97}	91.844 (4.05)	121.463 (3.91)	45.263 (1.56)	0.445 (1.93)	0.507 (1.85)
δ_{98}	104.675 (4.37)	134.613 (4.07)	55.270 (1.66)	0.454 (1.86)	0.495 (1.73)
δ_{99}	98.911 (3.76)	129.560 (3.61)	46.764 (1.31)	0.291 (1.15)	0.335 (1.13)
δ_{00}	102.979 (3.68)	134.279 (3.51)	43.591 (1.13)	0.205 (0.83)	0.265 (0.91)
δ_{01}	104.808 (3.62)	136.204 (3.47)	51.232 (1.25)	0.154 (0.60)	0.194 (0.64)
N	2667	2264	403	2264	1924

t-statistics are in parentheses. Standard errors account for clustering at the clinic level. We include the following controls in our regression models: *COMP* (in specification (1)), population of women age 25-44, educational achievement of women, average household size, percent Catholic, median income, percentage of women over age 16 in the labor force, and year dummies.

Table 8

Monopoly Clinic Success in Delaying Entry, 1992-2001

Dependent variable	Transition from monopoly to non-monopoly
Estimation method	Probit
Years since adoption (*YSA*)	-0.025 (-2.68)
Clinic characteristics	
Hospital	0.035 (1.11)
University	-0.019 (-0.57)
Age	-0.007 (-1.05)
N	280

Table entries are marginal probabilities. t-statistics are in parentheses. Standard errors account for clustering at the clinic level. We include the following controls in our regression models: Population of women age 25-44, educational achievement of women, average household size, percent Catholic, median income, percentage of women over age 16 in the labor force, and a time trend.

Figure 1
% of Markets with ICSI Available

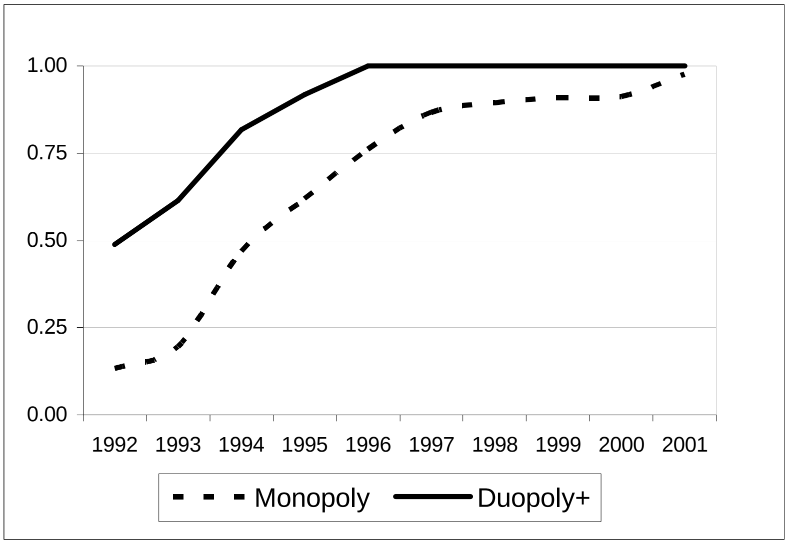

Figure 2
% of Clinics with ICSI Available