Organizational Barriers to Technology Adoption: Evidence from Soccer-Ball Producers in Pakistan*

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PRELIMINARY

Abstract

This paper studies technology adoption in a cluster of soccer-ball producers in Sialkot, Pakistan. Our research team invented a new cutting technology that reduces waste of the primary raw material. We allocated the technology to a random subset of producers. Despite the arguably unambiguous net benefits of the technology, after 15 months take-up remained puzzlingly low. We hypothesize that a key reason for the lack of adoption is a misalignment of incentives within firms: the key employees (cutters and printers) are typically paid piece rates, with no incentive to reduce waste, and the new technology slows them down, at least initially. Fearing reductions in their effective wage, employees resist adoption in various ways, including by misinforming owners about the value of the technology. To investigate this hypothesis, we implemented a second experiment among the firms to which we originally gave the technology: we offered one cutter and one printer per firm a lump-sum payment, approximately equal to a monthly wage, to demonstrate competence in using the technology in the presence of the owner. This incentive payment, small from the point of view of the firm, had a significant positive effect on adoption. We interpret the results as supportive of the hypothesis that misalignment of incentives within firms is an important barrier to technology adoption in our setting.

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1 Introduction

Careful observers of the process of technological diffusion have been struck by how slow it is for many technologies.[1] A number of the best-known studies of diffusion have focused on agriculture or medicine,[2] and in these sectors the slow adoption could potentially be explained by a lack of competitive pressure, but diffusion has been observed to be slow even for large firms in manufacturing. In a classic study of diffusion of 12 major industrial technologies, for instance, Edwin Mansfield found that it took more than 10 years for half of major U.S. iron and steel firms to adopt by-product coke ovens or continuous annealing lines.[3] More recently, Bloom et al. (2013) found that many Indian textile firms are not using standard (and apparently cheap to implement) "lean production" management practices that have diffused widely elsewhere. The surveys by Stoneman (2002), Hall and Khan (2003) and Hall (2005) give many more examples.

Why is adoption so slow for so many technologies? This question is key to understanding the process of economic development and growth. It is also a difficult one to study, especially among manufacturing firms. It is rare to be able to observe firms' technology use directly, even after the fact, and rarer still to have direct measures of the costs and benefits of adoption, or of what information firms have about a given technology during the diffusion process. As a consequence, it is difficult to distinguish between various possible explanations for low adoption rates.

In this paper, we present evidence from soccer-ball producers in Sialkot, Pakistan, that a conflict of interest between employees and owners within firms is an important barrier to adoption. The setting has two main advantages for understanding the adoption process. The first is that the industry is populated by a substantial number of firms — 135 by our initial count — producing a relatively standardized product and using largely the same, simple production process. The cluster produces 30 million soccer balls a year, or about 40 percent of world production, and 70 percent of world hand-stitched production (Wright, 2010). The second, and perhaps more important, advantage is that our research team, through a series of fortuitous events, discovered a useful innovation: we invented a new technology that represents, we argue, an unambiguous increase in technical efficiency for firms in the sector. The most common soccer-ball design combines 20 hexagonal and 12 pentagonal panels (see Figure 2). The panels are cut from rectangular sheets of an artificial leather called rexine, typically by bringing a hydraulic press down on a hand-held metal die. Our new technology, described in more detail below, is a die that increases the number of pentagons that can be cut from a rectangular sheet, by implementing the best packing of pentagons in a plane known to mathematicians. A

[1] For instance, in a well-cited review article, Geroski (2000) writes: "The central feature of most discussions of technology diffusion is the apparently slow speed at which firms adopt new technologies" (p. 604).

[2] See, for instance, Ryan and Gross (1943), Griliches (1957), Coleman and Menzel (1966), Foster and Rosenzweig (1995), and Conley and Udry (2010).

[3] See Mansfield (1961) and the summary in Table 2 of Mansfield (1989).

conservative estimate is that the new die reduces rexine costs for pentagons by 6.25 percent and reduces total costs by approximately 1 percent — a modest reduction but not an insignificant one in an industry where mean profit margins are 8 percent. The benefits of the new die can be demonstrated in 20 minutes and it requires minimal adjustments to other aspects of the production process.

We randomly allocated the new technology to a subset of 35 firms (which we refer to as the "tech drop" group) in May 2012. To a second group of 18 firms (the "cash drop" group) we gave cash equal to the value of the new die (US$300), and to a third group of 79 firms (the "no drop" group) we gave nothing. We initially expected the technology to be adopted quickly by the tech-drop firms, and we planned to focus on spillovers to the cash-drop and no-drop firms and the channels through which they operate; we pursue this line of inquiry in a companion paper (Atkin et al., 2014). In the first 15 months of the experiment, however, the most striking fact was how few firms had adopted, even among the tech-drop group. As of August 2013, five firms from the tech-drop group and one from the no-drop group had used the new die to produce more than 1,000 balls, our preferred measure of adoption. The experiences of the adopters indicated that the technology was working as expected; we were reassured, for instance, by the fact that the one no-drop adopter was one of the largest firms in the cluster, and had purchased a total of 32 dies on 9 separate occasions. But overall adoption remained puzzlingly low.

In our April 2013 survey round, we asked non-adopters in the tech-drop group why they had not adopted. Of a large number of possible responses, the leading answer was that the firm's cutters were not willing to work with the new die. We also noticed that the large adopter (purchaser of the 32 dies) differed from the norm for other firms in its pay scheme: while more than 90 percent of firms pay a pure piece rate, it pays a fixed monthly salary plus a performance bonus. The qualitative responses and the anecdote about the largest adopter led us to hypothesize that *a misalignment of incentives within the firm* is an important reason for the lack of adoption. The new die slows cutters down, certainly in the initial period when they are learning how to use it, and possibly in the longer run (although our data suggest that the long-run speed is nearly the same as for the existing die). If cutters are paid a pure piece rate, their effective wage will fall in the short run. The new die requires a slight modification to another stage of production, printing, and printers face a similar but weaker disincentive to adopt. Unless owners modify the payment scheme, the benefits of using the new technology accrue to owners and the costs are borne by the cutters and printers. Realizing this, the workers may find various ways to discourage owners from adopting. Below we formalize this intuition in a simple principal-agent model.

To investigate this hypothesis, we designed and implemented a second experiment. In September 2013, we randomly divided the set of tech-drop firms that were still in business into two groups, a treatment group (which we refer to as the A group) and a control group (the

B group). To the B group, we simply gave a reminder about the benefits of the die and an offer of another demonstration of the cutting pattern. To the A group, we gave the reminder but also explained to the owner the issue of misaligned incentives and offered an incentive-payment treatment: we offered to pay one cutter and one printer in each firm a lump-sum bonus roughly equivalent to a monthly wage (US$150 and US$120, respectively), conditional on each worker demonstrating competence in using the new technology within one month. The bonus payments were very small relative to total revenues from soccer-ball sales for the firms, which have a mean of approximately US$100,000 and a median of approximately US$30,000 per month. Of the 13 group-A firms that had not already adopted the new die, 8 accepted the incentive-payment intervention, and 4 subsequently adopted the new die. Of the 13 group-B firms that had not already adopted the new die, none subsequently adopted. Although these sample sizes are small, the positive effect on adoption is statistically significant. The fact that such small payments had a significant effect on adoption decisions suggests that the misalignment of incentives is indeed an important barrier to adoption in this setting.

The natural question that arises is why firms did not simply adjust their payment schemes to incentivize their employees to adopt the technology. We discuss possible reasons in more detail below, but briefly there appear to be three possible explanations. First, it may be that there are transaction costs involved in changing labor contracts, even if implicit as in this case. Second, it may be that many owners simply did not realize that such an alternative payment scheme was possible, just as the technical innovation had not occurred to them. Third, it may be that the employees, fearing a decline in their effective wage, have been misinforming owners about the value of the new technology, with the result that owners do not see an advantage in adopting. Anecdotal evidence suggests that this sort of misinformation has been occurring. Pinning down the precise mechanism leading firms not to offer new payment schemes will require additional work. What is clear, however, is that many firms did not in fact adjust the payment scheme, and for that reason there was scope for our modest payment intervention to have a positive effect on adoption.

In addition to the research cited above, our paper is related to several different strands of literature. A number of papers have highlighted resistance to adopting new technologies. Mokyr (1990) argues that medieval guilds blocked implementation of new technologies; Desmet and Parente (forthcoming) further suggest that this was due to small markets and lack of competition. Similarly, Parente and Prescott (1999) argue that monopoly rights in factor supplies can explain low levels of technology adoption across countries. The Bloom et al. (2013) paper mentioned above also suggests that a lack of competition may be responsible to the failure to adopt beneficial management practices.

Also related is a literature on organizations that has settings where changes to piece-rate contracts are necessary to align incentives between workers and managers. In an influential study, Holmstrom and Milgrom (1991) show that piece rates may not be optimal when workers must perform multidimensional tasks. High-powered incentives such as piece rates may induce employees to focus too much on the incentivized task, to the detriment of other tasks the employee might otherwise have been willing to carry out — which in our context would correspond to minimizing material waste or innovating along other dimensions. The fact that workers resist adoption in part by misinforming owners about the benefits of the technology suggest strategic communication plays a role when incentives are misaligned (e.g., Crawford and Sobel (1982)). Freeman and Kleiner (2005) provide case-study evidence for just such a trade-off. They study an American shoe company whose shift away from piece rates arguably helped it to respond to fierce competition from low-cost foreign producers.[4]

Our paper is also related to an active literature on technology adoption in agriculture (e.g., see Foster and Rosenzweig (1995), Bandiera and Rasul (2006), Conley and Udry (2010), Duflo et al. (2011), Suri (2011), and Hanna et al. (2012)). Our study shares with this literature that we have a clean measure of technology use, but it differs in its focus on larger manufacturing firms. We believe that the adoption decisions of larger manufacturing firms are important to understand in its own right, as they clearly matter for development and growth, but they are also interesting is that they involve issues of organizational conflict arise that when decision-makers are individual farmers.

The paper is organized as follows. Section 2 provides background on the Sialkot soccer ball manufacturing cluster. Section 3 describes the new cutting technology in detail. Section 4 describes our surveys and presents summary statistics on the industry. Section 5 details the roll out of the new technology to firms within the soccer ball cluster and documents rates of early adoption. Section 6 discusses some qualitative evidence on organizational barriers to adoption and presents a simple principal-agent model. Section 7 describes the incentive-payment experiment and evaluates the results. Section 8 concludes.

2 Industry Background

Sialkot, Pakistan is a city of 1.6 million people in the state of Punjab. The origins of the soccer-ball cluster date to British colonial rule (Sandal, undated). Soccer balls for British regiments were imported from England, but given the long shipping times, there was growing need to produce balls locally. In 1889, a British sergeant asked a Sialkoti saddlemaker to repair a damaged ball. The saddlemaker was a skilled leather cutter and instead manufactured a new ball that impressed the sergeant who placed orders for more balls. The industry subsequently expanded through spinoffs from the original firm and new entrants. By the 1970s, the city was

[4] Gibbons (1987) formalizes the related idea that workers will restrict output if they believe that managers will revise piece rates downwards in the future.

a center of offshore production for many European soccer ball companies, and in 1982, firms in Sialkot manufactured the balls used in the FIFA World Cup for the first time.

Virtually all of the Pakistan's soccer ball production is concentrated in Sialkot and exported to foreign markets. In recent years, the global market share of the cluster has been shrinking. Considering U.S. imports (for which, conveniently, there is a 10-digit Harmonized System category for inflatable soccer balls, 9506.62.40.80), Pakistan's market share fell from a peak of 71 percent in 1996 to 17 percent in 2012. In contrast, China's market share rose from 19 percent to 71 percent over the same period. (See Figure 1.) The firms in Sialkot face increasing pressure from Chinese producers at both the high and low ends of the soccer ball market. At the low end, China dominates production of lower-quality machine-stitched balls. At the high end, Chinese firms manufacture the innovative thermo-molded balls that have been used in recent FIFA World Cups. Sialkot still remains the major source for the world's hand-stitched soccer balls; it provided, for example, the hand-stitched balls used in the 2012 Olympic Games.

To the best of our knowledge, there were 135 manufacturing firms producing soccer balls in Sialkot as of November 2011. The firms themselves employ approximately 12,000 workers, and outsourced employment of stitchers in stitching centers and households is generally estimated to be more than twice that number (Khan et al., 2007). The largest firms have hundreds of employees (the 90th percentile of firm size among our sample is 225 employees) and typically produce for large international sports brands such as Nike and Adidas as well as under their own brands or for smaller country-specific brands. These firms manufacture both high-quality "match" and medium-quality "training" balls with a sports brand or soccer team's logo as well as lower quality "promotional balls" branded with an advertiser's logo. The remaining producers in our sample are small- and medium-size firms (the median firm size is 16 employees) who typically produce promotional balls either for clients met at industry fairs and online markets or under subcontract to larger firms.

3 The New Technology

3.1 Describing the technology

Before presenting our new technology, we first briefly explain the standard production process. As mentioned above, most soccer balls (approximately 90 percent in our sample) are of a standard design combining 20 hexagons and 12 pentagons (see Figure 2), often referred to as the "buckyball" design because of its resemblance to a geodesic dome designed by R. Buckminster Fuller. There are four stages of production. In the first stage, shown in Figure 3, an artificial leather called rexine is glued to layers of cloth (cotton and/or polyester) using a latex-based adhesive to form what is called a laminated sheet. The rexine, cloth and latex are the most expensive inputs to production, together accounting for approximately 55 percent of the total cost of each soccer ball (or more if imported rexine, which is higher-quality, is used instead of Pakistani rexine). In the second stage, shown in Figure 4, a skilled cutter uses a metal die and a hydraulic press to cut the hexagonal and pentagonal panels from the laminated sheets. The cutter positions the die on the laminated sheet by hand before activating the press with a foot-pedal. He then slides the laminated sheet along and places the die again to make the next cut.[5] In the third stage, shown in Figure 5, logos or other insignia are printed on the panels. This requires designing a "screen", held in a wooden frame, that allows ink to pass through to create the desired design. Typically the cutting process produces pairs of hexagons or pentagons that are not completely detached; the die makes an indentation but leaves them attached to be printed as a pair, using one swipe of ink. In the fourth stage, shown in Figure 6, the panels are stitched together around an inflatable bladder. Unlike the previous three stages, this stage is often outsourced, with stitching taking place at specialized stitching centers or in stitcher's homes. The production process is remarkably similar across the range of firms in Sialkot. A few of the larger firms have automated the cutting process, cutting half-sheets or full sheets of rexine at once, or attaching a die to a press that moves on its own, but even these firms typically continue to do hand-cutting for a share of their production. A few firms in the cluster have implemented machine-stitching, but this largely does not affect the first three stages of production.

Prior to our study, the most commonly used dies cut two panels at a time, either two hexagons or two pentagons. (See Figure 7.) Hexagons tessellate (i.e. completely cover a plane), and experienced cutters are able to cut with a small amount of waste — approximately 8 percent of a laminated sheet, mostly around the edges. (See the rexine "net" remaining after cutting hexagons in Figure 8.) Pentagons, by contrast, do not tessellate, and using the traditional two-pentagon die even experienced cutters typically waste 20-24 percent of the laminated sheet. (See Figure 9.) The leftover rexine has minimal little value; typically it is sold to brickmakers who burn it to fire their kilns.

In June 2011, as we were first exploring the possibility of studying the soccer-ball sector, we sought out a consultant who could recommend a beneficial new technique or practice that had not yet diffused in the industry. We found a Pakistan-based consultant who appears to have been responsible for introducing the existing two-hexagon and two-pentagon dies many years ago. (Previously firms had used single-panel dies.) We offered the consultant US$4,125 to develop a cost-saving innovation for us. The consultant spent several days in Sialkot but was unable to improve on the existing technology. After this setback, a co-author on this project, Eric Verhoogen, happened to watch a YouTube video of a Chinese firm producing the Adidas "Jabulani" thermo-molded soccer ball used at the 2010 FIFA World Cup. The video showed an automated press cutting pentagons for an interior lining of the Jabulani ball using a pattern

[5] All of the cutters, printers and owners we have encountered in the industry have been men.

different from the one we knew was being used in Sialkot. Based on the pattern in the video, Verhoogen and his wife, Annalisa Guzzini, an architect, developed a blueprint for a four-pentagon die. (See Figures 10 and 11.) We then contracted with a diemaker in Sialkot to produce the die. (See Figure 12.) It was only after we had received the first die and piloted it with a firm in Sialkot that we discovered that the cutting pattern has been known to mathematicians at least since Kuperberg and Kuperberg (1990) and, conveniently enough, appears on the Wikipedia "Pentagon" page.[6] (See Figure 13.)[7]

The pentagons in the new die are offset, with the two leftmost pentagons sharing half of an edge, unlike the traditional two-pentagon die in which the pentagons are flush, sharing an entire edge. We refer to the new die as the "offset" die, and treat other dies with pentagons sharing half of an edge as variations on our technology. Note that a two-pentagon variant of our design can easily be made using the specifications in the blueprint (with the two leftmost and two rightmost pentagons in Figure 10 cut separately). As we discuss in more detail below, the two-pentagon offset die is the one that has proven more popular with firms.

3.2 Benefits and costs of the new technology

We now turn to a calculation of the benefits and costs of using the new offset die. The dimensions of pentagons and hexagons vary slightly across firms, even for balls of a given official size (a size 5 ball being the standard for adults). The most commonly used pentagons have edge-length 43.5 mm, 43.75 mm or 44 mm after stitching. For 44 mm pentagons, an experienced cutter using the traditional die can typically cut 250-256 pentagons from a standard (39 in. by 54 in.) sheet of rexine. Using the offset die, it is possible to achieve 272, as illustrated in Figure 11. For 43.5 mm pentagons, an experienced cutter can typically cut 260-264 pentagons per rexine sheet. Using the offset die, it is possible to achieve 280. A conservative estimate of the rexine savings per pentagon from using the offset die is 6 percent.

Table 1 provides a cost breakdown of two medium-size firms in our sample that produce medium-quality (promotional) balls. The cost to the firm to produce a ball is around 300 Rupees (US$3). The laminated sheets account for approximately 55 percent of the cost of a ball.

[6] The cutting pattern represents the best known packing of pentagons into a plane. Kuperberg and Kuperberg (1990) conjecture that the pattern represents the densest possible packing of regular pentagons, but this is not a theorem.

[7] One might wonder whether firms in Sialkot have been also observed the production process in the Chinese firm producing for Adidas, since it was so easy for us to do so. We found one owner, of one of the larger firms in Sialkot, who said that he had been to China and observed the offset cutting pattern (illustrated in Figure 11) and was planning to implement it on a new large cutting press to cut half of a rexine sheet at once, a process known as "table cutting". As of May 2012, he had not yet implemented the new pattern, however, and he had not developed a hand-held offset die. It is also important to note that two of the largest firms in Sialkot have not allowed us to see their production processes. As these two firms are known to have also produced for Adidas, we suspect that they were aware of the offset cutting pattern. What is clear, however, is that neither the offset cutting pattern nor the offset die were in any other firm we have visited as of the beginning of our experiment in May 2012.

Because the standard design uses more hexagons than pentagons, and because each hexagon has larger area than each pentagon, pentagons account for only 33 percent of laminated sheet costs. Together, these numbers imply a total cost reduction of 1.10 percent ($0.06 \times 0.33 \times 0.55 = .011$) due from using the offset die.

The new die requires that the cutters are more careful in the placement of the die while cutting. An extremely conservative estimate of the increase in labor time for cutters is 50 percent. (Below we discuss why this number is conservative.) Table 1 indicates that labor costs for cutting represent less than .7 percent of total costs. Keeping in mind that pentagons represent one-third of rexine costs, a conservative estimate of the cost increase due to increased labor time for cutters is .11 percent ($0.50 \times 0.007 \times 0.33 = .0011$). Anecdotally, a number of printers complained that the fact that the two-pentagon pieces produced by the offset die are more difficult to print than those produced by the traditional die, but we found during our incentive-payment experiment (see Section 7 below) that printers' speed was essentially the same. We therefore do not factor in an increase in labor time for printers. Subtracting the labor cost increases from the material cost savings produces a net variable cost reduction of approximately 1 percent per ball. Although this number is small in absolute terms, it is not trivial in an industry with mean profit margins of 8 percent.

There are a number of fixed costs of adopting the offset die, but they are modest in monetary terms. First, the firm must purchase the die itself. We were charged Rs 30,000 (US$300) for a four-piece die; the market price for a two-pentagon offset die is now about Rs 10,000 ($100). As we explain below, we paid this fixed cost for the firms in the tech-drop group, to which we gave the new die initially. Second, the existing screens used to print logos and branding on the panels must be re-designed and re-made to match the offset pattern. Designers typically charge Rs 600 (US$6) for each new design; for the minority firms that do not have in-house screenmaking capabilities, a new screen costs Rs 200 ($2) to buy from an outside screenmaker. Third, some firms use a combing machine, a device that punches holes at the edges of panels to facilitate sewing. It is always possible to use a single-pentagon machine, but there is benefit in terms of speed to using a two-pentagon combing machine. A two-pentagon combing machine that works with pentagons cut by the two-pentagon offset die costs approximately Rs 10,000 (US$100).Adding together these three components, a conservative estimate of total fixed costs is Rs 20,800 (US$208). These fixed costs could be recouped through variable cost reductions on production of 7,000 or more balls ($208/[0.01 \times 3] = 6,933$). The median firm in our sample manufactures about 10,000 balls per month, so these numbers imply that the median firm would break even on the new technology after approximately three weeks of use.

As mentioned above, the setting and our technology have a number of advantages for the purpose of studying adoption. First, virtually all firms in the cluster cut hexagons and pentagons in the manner described above, at least for some portion of their production. Second, it is straightforward to measure whether firms are using the technology, either by observing the cutters directly or by inspecting the discarded rexine nets. We have also received independent reports of sales of the offset dies from the independent diemakers in Sialkot. Third, the new die requires minimal changes to other aspects of production. Apart from the combing machine issue described above, the main required change is to the printing designs and screens. Fourth, the new technology is easy to disseminate. In all firms we gave the technology to, a cutter was able to cut 272 pentagons or more within 30 minutes (although at a slower rate than using the traditional die, as we will discuss below.) It can be explained and demonstrated in thirty minutes. Fifth, the uncertainty about the productivity benefits of the technology seems limited. Once an owner sees the number of pentagons that can be cut from each sheet, it is straightforward to calculate the cost reduction from adoption. It may be that the owner believes that there are hidden problems with the technology that are not revealed in the demonstration, of course; we return to this issue below. Finally, from the cost calculations above, it seems clear that the net benefits of the technology are positive for any firm expecting to produce more than an extremely modest number of balls.

4 Survey and Summary Statistics

Between September and November of 2011, we conducted a listing exercise of soccer-ball producers within Sialkot. We found 157 producers that we believed were active in the sense that they had produced soccer balls in the previous 12 months and cut their own rexine. Of the 157 firms on our initial list, we subsequently discovered that 22 were not active by our definition. Of the remaining 135 firms, 3 served as pilot firms for testing our technology and providing the detailed information on costs provided in Table 1.

We carried out a baseline survey between January and April 2012. Of the 132 active non-pilot firms, 85 answered the survey; we refer to them as the "initial responder" sample. The low response rate was in part due to negative experiences with previous surveyors.[8] In subsequent survey rounds our reputation in Sialkot improved and we were able to collect information from an additional 31 of the 47 non-responding producers (the "late responder" sample), to bring the total number of respondents to 116. The baseline collected firm and owner characteristics, standard performance variables (e.g. output, employment, prices, product mix, inputs) and information about firms' networks (supplier, family, employee and business networks). To date, we have conducted seven subsequent survey rounds, in May-June 2012, July 2012, October 2012, January 2013, March-April 2013, September-November 2013 and January-March 2014. The follow-up surveys have again collected information on the various performance measures as

[8] In 1995, a number of soccer ball producers were interviewed by an external team and the material was subsequently used for a story exposing the use of child labor in the industry. Firms were initially quite distrustful of us in part for that reason.

well as information pertinent to the adoption of the new cutting technology.

Table 2 presents summary statistics on various firm characteristics, including means and values at several quantiles. Panel A reports statistics for the sample of 85 baseline responders and Panel B for the full sample that also includes the 31 late responders. Because the late responders did not respond to the baseline, we have a smaller set of variables for the full sample. Because firms' responses are often noisy, where possible we have taken within-firm averages all survey rounds for which we have responses (indicated by "avg. ..." at the beginning of variables in the table). Focusing on the initial-responder sample for now, a number of facts are worth emphasizing. The median firm is medium-size (20 employees, producing 10,000 balls/month) but there are also some vary large firms (maximum employment is 1,700, producing nearly 300,000 balls per month).[9] Profit rates are generally low, approximately 8 percent at the median and 12.5 percent at the 90th percentile. For most firms, all or nearly all of their production of size-5 balls uses the standard "buckyball" design. The industry is relatively mature; the mean firm age is 25.4 years, 19.5 years at the median and 54 years at the 90th percentile. Finally, cutters tend to have high tenure; the mean tenure in the current firm for a head cutter is approximately 11 years (9 years at the median). One other fact, which will be salient below, is that the vast majority of firms pay pure piece rates to their cutters and printers. Among the initial responders, 77 of 85 firms pay a piece rate to their cutters, with the remainder paying a daily, weekly or monthly salary and possibly performance bonuses.[10] Table A.1 in the appendix shows how the same variables very across firm-size bins for the initial-responder and full samples.

5 Experiment 1: The Technology-Drop Experiment

5.1 Experimental Design

Here we briefly describe the randomization procedure for our first experiment, the technology-drop experiment. (Additional details are provided in Atkin et al. (2014).) The 85 firms in the initial-responder sample were divided into four strata based on quartiles of the number of balls produced in a normal month from the baseline survey. Within these strata firms were randomly assigned to one of three groups: the tech-drop group, the cash-drop group, and the no-drop group. The top panel of Table 3 summarizes the distribution of firms across groups for the initial-responder sample. In each stratum, 6 firms were assigned to the technology group, 3 to cash group and 13 to the nothing group.[11] In addition, because we were interested in tracking all firms in the cluster, we treated initial non-responders as a separate stratum and divided

[9]The employment numbers understate the true size of the industry since the most labor intensive stage of production, stitching, is almost exclusively done outside of the firm in stitching centers or homes.

[10]In a later survey round, we also found that more than 90 percent of firms pay their printers a piece rate.

[11]There were 88 firms with 22 in each strata at the moment of assignment; however, three firms that responded to our baseline survey either shut down or were later revealed not to be firms by our definition, leaving 85 firms.

into three groups using the same proportions as for the initial responders. Of the initial non-responders, 22 were revealed not to be active firms. Of the remaining 47 firms, 31 eventually responded to at least one of our survey rounds; these are the "late responders" included in the full sample discussed in Section 4. The bottom panel of Table 3 summarizes the response rates for the initial non-responders. It is important to note that response rates of the active initial non-responders are clearly correlated with treatment assignment: firms assigned to the tech-drop and cash-drop groups (to which we were giving the new die or cash, as described below) were more likely to respond that firms assigned to the no-drop group. For this reason, when it is important that assignment to treatment in the tech-drop experiment be exogenous, we will focus on the initial-responder sample.

We began the tech-drop experiment in May 2012. Firms assigned to the technology group were provided with a four-pentagon offset die, along with a blueprint that could be used to modify the die. Additionally, these firms were given a thirty-minute demonstration of the cutting pattern for the new die. The die we provided cuts pentagons with edge-length (after sewing) of 44 mm. As noted in Section 3 above, firms often use slightly different size dies, and the pentagon die size must match the hexagon die size. For this reason, we also offered firms a free trade-in: we offered to replace the die we gave them with an offset die of a different size, produced at a local diemaker of their choice. Firms were also able to replace their die with a 2-panel version of the offset die if they chose to. Of the 35 tech-drop firms, 19 took us up on the trade-in offer. The firms in the cash-drop and no-drop groups were not provided with the new technology. The cash group was given the cash equivalent of the die, which amounted to Rs 30,000 (US$300).[12] Firms in the no-drop group were not given anything.

To examine baseline balance, Panel A of Table 4 reports the mean of various firm characteristics across the tech-drop, cash-drop and no-drop groups for the initial-responder sample. We find no significant differences across groups.[13] It appears that the randomization did generate exogenous variation in initial exposure among the initial responders. Panel B of Table 4 reports the analog for the 31 late responders. Here we see significant differences for various variables, consistent with the observation above that response rates among the late responders appear to have responded endogenously to treatment assignment. Caution is clearly warranted in interpreting the results including the late responders.

5.2 Early adoption of the new technology

We have continued to monitor closely the technology use of all firms in the cluster, in addition to other variables. The first post-baseline survey round was carried out at the time of the

[12] We included a cash treatment group to ensure that any differences in adoption between the technology and control groups was not simply due to credit constraints.

[13] On average, firms in the technology group employ fewer people than other firms, but the differences are not statistically different at the 5 percent level.

technology roll-out, during May-June 2012. As noted above, we have also carried out survey rounds in July 2012, October 2012, January 2013, March-April 2013, September-November 2013 and January-March 2014. The January 2013 and January-March 2014 round were carried out on the phone, and the other rounds in person. We assigned numbers 0-6 to these rounds.

In tech-drop group, we have explicitly asked about usage of the offset die. For the other groups, we have sought to determine whether firms are using the offset die without explicitly mentioning the offset die, through four methods. First, in our surveys we asked whether the firm recently adopted any new technologies or production processes. If they reported adopting a new cutting technology, we asked them to describe it further. Second, we asked for the number of pentagons cut per sheet and queried further if these numbers had risen from previous rounds. Third, our survey team was attentive to any mention of the offset die in the factory, whether or not in the context of the formal survey. Fourth, we have maintained independent contact with the six diemakers in Sialkot, who have agreed to provide us information on sales of the offset die. Based on this information, we believe that we have complete knowledge of offset dies purchased in Sialkot, even by firms that have never responded to any of our surveys. Any firm who appears in the diemakers' registers as having received an offset die was asked directly about usage. If we had evidence that the firm adopted any variant of the offset die through any of the four sources above, we asked additional questions to learn more details about the adoption process and information flows pertaining to the die.

Table 5 reports adoption rates among the initial responder sample as of August 2013, 15 months after we introduced the technology, with the initial-responder sample in Panel A and the full sample in Panel B. The first three rows of each panel indicate the number of potential adopters. The fourth row reports that a high proportion of tech-drop firms took up our offer of a trade-in for a different die. The fifth row reports the number of firms that ordered dies (beyond the one trade-in offered to tech-drop firms). The numbers are modest: in the full sample, five no-drop firms and one tech-drop firm made an additional order. (In one case, the diemaker was slow in delivering the die and firm canceled its order, hence the discrepancy between the fifth and sixth rows).

In measuring adoption of the technology, we face a choice about whether to require that the offset die was used in the production of some minimum number of balls and what bound to use. Several firms reported that they had experimented with the die but had not actually used it for a client's order. To be conservative, we have chosen not to count such firms as adopters. Our preferred measure of adoption requires that firms have produced at least 1,000 balls with the offset die. The measure is not particularly sensitive to the lower bound; any bound above 100 balls would yield similar counts of adopters.

Using our preferred measure of adoption, the seventh and eighth rows of Table 5 report the number of firms who had ever adopted the offset die and the number who were currently using the die and had produced at least 1,000 balls with it in Aug. 2013, respectively. In the full sample, there were five adopters in the tech-drop group and one in the no-drop group.[14] In the initial-responder sample, the corresponding numbers are four and zero. The number of adopters as of Aug. 2013 struck us as small. Given the apparently clear advantages of the technology discussed above, we were expecting much faster take-up among the firms in the tech-drop group, to whom we had given the blueprint and the demonstration and for whom we had paid the fixed cost of the die.

5.3 Examining alternative explanations for low adoption

In this sub-section, we examine several standard hypotheses that may explain limited adoption of the offset die. We focus on data available to us in Aug. 2013, before we began the second experiment. We emphasize that this is primarily a descriptive exercise; we are not placing a causal interpretation on the correlations we observe in the data.

In many previous studies of technological diffusion, the presumption has been that firms do not adopt because they do not know about a technology. This is the assumption underlying "epidemic" models of diffusion, of the two main categories of diffusion reviewed by Geroski (2000). While lack of knowledge about the technology may explain the lack of take-up in the cash-drop and no-drop groups,[15] we know that this cannot be the explanation for low adoption among the tech-drop group, because we gave them the technology. We ourselves manipulated their information set.

Another natural hypothesis is simply that the technology does not reduce variable costs as much as we have argued that it does. It is possible that there are unobserved problems with the die that we were not aware of. Beyond our arguments about the mathematical superiority of our cutting design, a key piece of evidence against this hypothesis is the revealed preference of the six firms who adopted. In particular, the one adopter in the no-drop group, which we refer to as Firm Z, is one of the largest firms in Sialkot. This firm ordered 32 offset dies on 9 separate purchasing occasions between May 2012 and Aug. 2013, and has order more dies since then. Figure 14 plots the timing and quantity of its die orders. In March-April 2013 (round 4 of our survey) the firm reported that it was using the offset die for approximately 50 percent of its production, and has since reported that the share has risen to 100 percent. Since the firm had plenty of time to evaluate the efficacy of the offset die and subsequently placed multiple additional orders, it is hard to rationalize the firm's purchases and subsequent intensive use of the offset die if the offset die was not profitable for this firm.

[14] Recall that only the technology group was provided with the technology, and so any adoption among the other two groups constitutes a spillover. Atkin et al. (2014) investigates spillovers and the channels through which they operate.

[15] We have collected information on knowledge flows between firms, and Atkin et al. (2014) investigates them in more detail.

A third, related hypothesis is that the fixed costs are larger than we have portrayed them to be and are only worth paying if a firm produces at sufficient scale, which may be larger than many firms in Sialkot. A fourth hypothesis is that firms who specialize in higher quality balls — and hence use higher-quality imported rexine — may have stronger incentives to adopt, since rexine accounts for a larger portion of their unit costs. To examine these hypotheses, Table 6 estimates from a linear probability model relating adoption to firm characteristics related to scale and quality. We find little evidence that either scale or quality matters for the adoption decision. There is a marginally significant relationship between output and adoption for non-tech-drop firms, but this is due entirely to the fact that the one non-tech drop adopter is a large firm. Within the tech-drop group, there is no significant relationship between scale and adoption. Nor is the share of balls that use the standard "buckyball" design (captured by the "share standard (of size 5)" variable) significantly associated with adoption. The one quality-related variable that has a marginally significant relationship with adoption, the price of size 5 training balls, has a negative coefficient, opposite to what one would expect based on the fourth hypothesis above. The only variable that appears to be significantly associated with adoption is assignment to the tech-drop treatment in the first place.

A fifth hypothesis is that firms differ in managerial talent, and that only talented managers either identify the gains from the new technology or are able to implement the new technology in an efficient way. A sixth, related hypothesis is that adoption depends on worker skill, especially of the cutter. Table 7 reports results of linear models with several measures of manager and worker characteristics as covariates. There is no evidence that manager or cutter characteristics matter for adoption.

Given the small number of adopters as of Aug. 2013, it is perhaps not surprising that we have not found robust correlations with firm characteristics. But we do interpret the results of this sub-section as deepening the mystery of why so few firms adopted the new die.

6 Organizational Barriers to Adoption: Motivation and Model

[This section is still work in progress.]

6.1 Qualitative evidence

Puzzled by the lack of adoption, in the March-April 2013 survey round we added a question asking technology group firms to rank the reasons for why they had not adopted the new technology, providing nine options (including an "other" category).[16] Table 8 reports the responses

[16] The question asked respondents to "select the main reason(s) why you are not currently using an offset die. If more than one, please rank those that apply in order" The 9 categories were: (1) I have not had any orders to try out the offset die. (2) I have been too busy to implement a new technology. (3) I do not think the offset die

for the 18 tech-drop firms that responded. Ten of the 18 firms reported that their primary reason for not adopting was that their "cutters are unwilling to work with the offset die". Four of the 18 said that their primary problem related to "problems adapting the printing process to match the offset patterns" and five more firms selected this as the second-most important barrier to adoption. This issue may be related to the technical problem of re-designing printing screens, but as noted above the cost of a new screen from an outside designer is approximately US$6. It seems likely that the printing problems were also related to resistance from the printers. (The other popular response to the question, to which most firms gave lower priority, was that the firm had received insufficient orders, consistent with the scale hypothesis above.) The responses to the survey question were consistent with anecdotal reports from several owners that they had been dissuaded from adopting the new technology by negative reports about the technology from their cutters and printers. In the period after the roll-out of the experiment, one other piece of anecdotal evidence stood out. As noted above, more than 90 percent of firms in Sialkot pay piece rates to their cutters. One notable exception is the firm we have called Firm Z, the large adopter from the no-drop group. For several years, this firm had been paying a guaranteed monthly salary supplemented by a performance bonus.

6.2 A model of organizational barriers to adoption

The survey results and anecdotes point to misaligned incentives within the firm an explanation for limited technology adoption. If firms pay piece rates and do not modify the payment scheme when adopting, the gains from adoption of the new technology are enjoyed by the owner, who faces lower input costs, but the costs of adoption, in the form of increased labor time, are borne by cutters and, to a lesser extent, printers. While these costs are modest from the point of view of the firm, as we have argued above, they may lead to a substantial decline in income for the workers, certainly during the initial phase of learning to use the new die, and possibly in the longer run. If the cutters and printers do not expect owners to change the payment scheme they face, they have an incentive to resist adoption of the new technology.

We now develop a principal-agent model that captures this intuition and motivates our second experiment, which we present below in Section 7.[17] This first pass at the model is very simple, but it is rich enough to represent what we believe are the main forces at play. Specifically, it shows that there may exist a scenario in which an owner, acting rationally, may choose not to adopt a beneficial technology due to resistance from the cutter (who also acts rationally). We then

will be profitable to use. (4) I am waiting for other firms to adopt first to prove the potential of the technology. (5) I am waiting for other firms to adopt first to iron out any issues with the new technology. (6) The cutters are unwilling to work with the offset die. (7) I have had problems adapting the printing process to match the offset patterns. (8) There are problems adapting other parts of the production process (excluding printing or cutting problems) (9) Other [fill in reason].

[17]We thank Daniel Rappoport and Florian Ederer for useful discussions regarding the model.

describe an organizational innovation to the contract that alleviates the misaligned-incentives problem and which closely maps to the incentive-payment experiment described below.

We consider a one period game. There is a principal (she) and an agent (he). The agent produces output $q = sa$ where s is the productivity of the technology (e.g. the cuts per minute or speed), and a is effort. The agent expends effort at a cost of $e(a) = \frac{a^2}{2}$. The agent can also costlessly resist and cause H harm to the firm and he can credibly commit in advance to carry out this threat. The principal can sell output at a price p. The principal incurs two costs: a constant marginal cost of materials $C(q) = cq$ and a wage $w(q, .)$ that she pays to the agent. The principal's payoff is therefore given by $pq - w(q, .) - cq$.

Linear wage contracts

We initially assume that contracts must be of the form $w(q) = \alpha + \beta q$. We further assume that the agent has limited liability, $\alpha \geq 0$, a reasonable assumption given that no worker in our setting pays the principal to work in the factory.

There is a new technology n. The new technology affects the agent's productivity s and the material cost c. The old technology o has known parameters (s_o, c_o). The new technology is known by all parties to be slower ($s_n < s_o$); this can be thought of as a learning period where efficiency is low. The principal and agent are uncertain about the the material cost savings generated by the new technology. The new technology can have cost $c_1 < c_o$ (a potential improvement) or the same cost as the old technology c_o (in which case it is dominated by the old technology given the lower speed). The principal and agent have a common prior that the probability is θ that the new technology has cost c_1 and $1 - \theta$ that it has cost c_o.

The timing of the game is as follows. In Stage 1, the principal chooses a wage contract (α,β). In Stage 2, the agent chooses whether or not to resist adoption. In Stage 3, the principal decides whether or not to adopt the new technology and the parameters are revealed. In Stage 4 profits (including harm inflicted by the agent) and payments are realized.

Solving the game backwards, in Stage 3 the principal will decide to adopt if her expected profits are higher from doing so. From the incentive compatibility constraint, $a_i = \arg\max_a \alpha + \beta s_i a - \frac{a^2}{2}$, hence the agent will provide $a_i = \beta s_i$ effort where i indexes the technology. If the agent has committed to resisting the technology in Stage 2, she will adopt the new technology if:

$$\theta(ps_n a_n - (\alpha + \beta s_n a_n) - c_1 s_n a_n) + (1 - \theta)(ps_n a_n - (\alpha + \beta s_n a_n) - c_o s_n a_n) - H$$
$$> ps_o a_o - (\alpha + \beta s_o a_o) - c_o s_o a_o$$

If the agent has not committed to resisting the technology in Stage 2, she will adopt the new technology if:

$$\theta(ps_n a_n - (\alpha + \beta s_n a_n) - c_1 s_n a_n) + (1-\theta)(ps_n a_n - (\alpha + \beta s_n a_n) - c_o s_n a_n)$$
$$> ps_o a_o - (\alpha + \beta s_o a_o) - c_o s_o a_o$$

Note that a Stage 2 commitment by the agent to resist makes the principal strictly less willing to adopt the technology.

Knowing that adoption declines in H, in Stage 2 the agent may commit to harming the firm if the new technology is adopted. The agent prefers the new technology if his utility is higher. He will prefer the new technology if

$$\begin{aligned} \alpha + \beta s_n a_n - \frac{a_n^2}{2} &> \alpha + \beta s_o a_o - \frac{a_o^2}{2}, \\ s_n &> s_o \end{aligned}$$

and prefers the old technology otherwise. Since we are assuming that $s_n < s_o$, the agent never prefers the new technology for a given wage contract. He will always threaten to harm the firm if the new technology is adopted (or be indifferent about harming the firm if the potential benefits are so large to the owner that she will always adopt—for simplicity we assume the agent also harms the firm in this case).

In Stage 1, the principal chooses the optimal contract. Given that, under our assumptions, the agent will always commit in Stage 2 to harm her if she adopts the technology, the principal faces just two relevant branches of the game tree: a first in which she does not adopt and the agent does not harm her and a second in which she adopts and the agent harms her. On the first branch, she maximizes:

$$\begin{aligned} \max_{a,\beta} \quad & ps_o a - (\alpha + \beta s_o a) - c_o s_o a && \text{s.t.} \\ & \alpha + \beta s_o a - \tfrac{a^2}{2} && \geq \bar{u} \quad \text{(PC)} \\ & \arg\max_a \alpha + \beta s_o a - \tfrac{a^2}{2} && = a \quad \text{(ICC)} \\ & \alpha && \geq 0 \quad \text{(LLC)} \end{aligned}$$

As is well known in a principal-agent setting, in the absence of the limited-liability constraint, the principal will set $\beta = p - c_o$ and bring the agent down to his reservation utility through a negative value of α. With the limited-liability constraint this is not possible; since the agent's effort is independent of α, the principal will choose to set $\alpha = 0$. Feeding the optimal effort ($a \equiv a_o = \beta s_o$) from the incentive-compatibility constraint into the maximization and solving for β we obtain the optimal contract on this branch:

$$\alpha_o = 0,\ \beta_o = \frac{p - c_o}{2} \tag{1}$$

On the second branch of the game tree, the principal maximizes:

$$\max_{a,\beta} \quad \theta(ps_n a_n - (\alpha + \beta s_n a_n) - c_1 s_n a_n) + (1-\theta)(ps_n a_n - (\alpha + \beta s_n a_n) - c_o s_n a_n) - H$$

where $a_n = \beta s_n$ from the incentive-compatibility constraint once again. The optimal contract lies in between the optimal contracts for the two potential costs associated with the new technology, c_1 and c_o:

$$\alpha_n = 0,\ \beta_n = \frac{p - [\theta c_1 + (1-\theta)c_o]}{2} \tag{2}$$

When will the principal choose contract (1) and go down the first branch of the game tree, not planning to adopt, and when will she choose contract (2) and go down the second branch, planning to adopt? The choice depends depends on the capacity of the agent to harm her and her own prior about the cost advantage of the new technology. It is straightforward to show that she will choose (1) and not adopt if:

$$H > \frac{s_n^2 \left[\frac{p-(\theta c_1 + (1-\theta)c_o)}{2}\right]^2 - s_o^2 \left[\frac{p-c_o}{2}\right]^2}{2} \tag{3}$$

Note that as $\theta \to 0$, the right hand side goes to zero and any positive capacity to harm will lead the principal not to adopt.

Conditional wage contracts

Now suppose there exists an additional type of contract that pays an lump-sum incentive payment that depends on the cost advantage of the technology:

$$w(q) = \alpha + \beta q + \gamma \qquad \text{if } c = c_1$$

$$w(q) = \alpha + \beta q \qquad \text{if } c = c_o$$

Working through the game tree again, in Stage 3 the principal adopts the new technology if

$$\theta(ps_n a_n - (\alpha + \beta s_n a_n + \gamma) - c_1 s_n a_n) + (1-\theta)(ps_n a_n - (\alpha + \beta s_n a_n) - c_o s_n a_n) - H$$
$$> ps_o a_o - (\alpha + \beta s_o a_o) - c_o s_o a_o$$

if the agent tries to block the technology and harms the firm or

$$\theta(ps_n a_n - (\alpha + \beta s_n a_n + \gamma) - c_1 s_n a_n) + (1-\theta)(ps_n a_n - (\alpha + \beta s_n a_n) - c_o s_n a_n)$$
$$> ps_o a_o - (\alpha + \beta s_o a_o) - c_o s_o a_o$$

if the agent does not.

In Stage 2, once more the agent weakly prefers adoption of the new technology if his expected utility is higher:

$$\begin{aligned} \alpha + \beta s_n a_n - \frac{a_n^2}{2} + \theta\gamma &\geq \alpha + \beta s_o a_o - \frac{a_o^2}{2} \\ \gamma &\geq \frac{\beta^2}{2\theta}(s_o^2 - s_n^2) \end{aligned} \tag{4}$$

Therefore, if γ is greater or equal to this threshold, the agent will not commit to resisting adoption in Stage 2. Otherwise, as before, he will threaten to harm the firm if the principal adopts.

Knowing this, we solve for the principal's choice of wage contract in Stage 1. The principal again faces two branches of the game tree, a first that does not lead to adoption and a second that does. On the former branch, the optimal α_o and β_o are unchanged from before. On the latter branch, the optimal α_n and β_n are also the same as before, since the availability of the additional incentive, γ, does not change the optimal incentive contract. However, the principal has the additional option of offering a γ that satisfies (4) to induce the agent not to resist adoption.

Suppose that we are in the more interesting case where (3) holds (and the principal would not adopt if limited to linear contracts). Is there a region of the parameter space in which adoption will occur? The principal will choose the second branch of the game tree, and eventually adopt, if:

$$\begin{aligned} &\theta(ps_n a_n - (\alpha + \beta s_n a_n + \gamma) - c_1 s_n a_n) + (1-\theta)(ps_n a_n - (\alpha + \beta s_n a_n) - c_o s_n a_n) \\ &\qquad > ps_o a_o - (\alpha_o + \beta_o s_o a_o) - c_o s_o a_o \end{aligned} \tag{5}$$

Note that the principal has no incentive to choose a γ above the bound in (4) and will, if she chooses to offer the incentive, choose γ equal to the bound. Using this fact and rearranging (5), it can be shown that the principal will offer the γ incentive, the agent will not resist, and adoption will occur if:

$$\beta_n^2(s_o^2 - s_n^2) < s_n^2\beta_n^2 - s_o^2\beta_o^2$$

The value of conditional wage contracts

If we compare the expected profits under the two scenarios we can obtain the maximal amount the principal is willing to pay, G, to use the conditional wage contract before Stage 1. Focusing once more on the interesting case where the principal adopts with the conditional contract and does not adopt with the unconditional contract:

$$\theta(ps_n a_n - (\alpha_n + \beta_n s_n a_n + \gamma_n) - c_1 s_n a_n) + (1-\theta)(ps_n a_n - (\alpha_n + \beta_n s_n a_n) - c_o s_n a_n) - G$$
$$> ps_o a_o - (\alpha_o + \beta_o s_o a_o) - c_o s_o a_o$$

or

$$G \quad < \quad s_n^2 \beta^2 - \frac{s_o^2}{2}(\beta_o^2 + \beta^2).$$

Thus, this model captures two reasons why the principal may not adjust labor contracts to induce the agent not to resist the technology. One is that she is simply not aware of the availability of the incentive contract (involving γ). The other is that there is a transaction cost of offering such a contract that is greater than the value of the contract to her, G.

7 Experiment 2: The Incentive-Payment Experiment

7.1 Experimental design

To test the hypothesis a conflict of interest with firms tends to hinder adoption, in Sept.-Nov. 2013 we conducted a second experiment in which we altered the incentives facing cutters and printers, which we refer to as the incentive-payment experiment. Because we were interested in providing incentives for using the offset die, and because we wanted to avoid interfering with the process of diffusion of knowledge to the non-tech-drop firms from the first experiment, we focused on the 35 tech-drop firms to which we gave the blueprint and die. Of these, at the time of randomization, we believed that 34 of these firms were active. These were divided into the four similarly-sized strata: (1) firms in the two smaller strata from the tech-drop experiment that had not adopted the die as of Aug. 2013, (2) firms in the two larger strata from the tech-drop experiment that had not yet adopted the die, (3) firms from the initial non-responder stratum from the tech-drop experiment that had not yet adopted the die, and (4) firms that had already adopted the die. Within each stratum, firms were randomly assigned in equal proportion to a treatment group (which we call Group A) and a control group (Group B). Three of the 34 assigned firms were subsequently revealed to have stopped manufacturing balls, leaving 15 firms in Group A and 16 in Group B.

To firms in Group B we gave a refresher on the offset die and the new cutting pattern. We offered to do a new demonstration with their cutters. We also informed each firm about the two-pentagon variant of the offset die; as noted above, the variant had proven more popular than the four-pentagon offset die we originally distributed.

To each firm in Group A, we gave the same refresher, the same offer of a new demonstration, and information about the two-pentagon variant. In addition, we explained to the owner the issue of misaligned incentives and offered a new incentive-payment scheme. Specifically, we offered to pay one cutter and one printer lump-sum bonuses roughly equivalent to their monthly incomes — 15,000 Rs (US$150) and 12,000 Rs (US$120), respectively — on the condition that within one month the cutter demonstrate competence in using the new die and the printer in printing pairs of offset pentagon pieces cut by the new die. We explained that cutters and printers on piece-rates had an incentive to misinform the owner about the value of the technology and that a payment scheme such as the one we offered was more likely to elicit cooperation from the employees. If the owner agreed to the intervention, we paid 1/3 of the incentive payment to the cutter and printer on the spot and scheduled a time to return to test their performance using the die.[18] The performance target for cutters was to cut 272 pentagons from a single sheet in three minutes using the new die. The target for the printer was to print 48 pairs of pentagons cut by the offset die in three minutes.[19] We provided the owner with 20 laminated sheets for his workers to practice with, printing screens for offset pentagon pairs, and a nominal Rs 5,000 ($50) to cover additional costs such as overhead (e.g. electricity while the cutters were practicing). We returned after approximately one month to test the employees and, upon successful achievement of the performance targets, to pay the remaining 2/3 of the incentive payments. Without revealing ahead of time that we would do so, we allowed for a buffer of 30 seconds and 5 pentagons for cutters and 30 seconds for printers.[20]

Table 9 evaluates baseline balance by comparing firm characteristics across Group A and Group B firms at the time of our visit to explain the intervention (Sept. 2013). No differences in means are statistically significant. It appears that randomization was successful.[21]

[18]To the extent possible, we attempted to make the payment directly to the cutter and printer. In a couple of cases, the owner insisted that we pay him and he would pass on the money to the employees, and we acceded to this request.

[19]The 3-minute targets were chosen after conducting speed tests at the two pilot firms mentioned in section 5. They are approximately one third higher than the time to cut a single sheet using the original die and the time to print 48 two-pentagon panels cut in using the original die.

[20]That is, the effective target for cutters was 267 pentagons from one sheet in 3 minutes 30 seconds, and for printers was 48 pairs in 3 minutes 30 seconds.

[21]Because of an error by our enumerators, one firm that was supposed to be in Group B was offered the incentive-payment intervention. This occurred while two co-authors of the paper were in the field, and the error was caught within hours of its occurrence. To maintain balance, we randomly selected one as-yet-untreated Group A firm from the same stratum and re-assigned it to Group B.

7.2 Results

Ten of the 15 Group A firms agreed to participate in the experiment.[22] Table 10 reports the times achieved by the cutter at each firm. The average time was 2 minutes and 52 seconds, approximately 27 percent longer than the average time to cut with the traditional die (2 minutes and 15 seconds). Partly for this reason we believe that the 50 percent increase in labor time factored into the cost calculations above in Section 3 is conservative. In addition, many cutters expressed confidence that with additional use they could lower their average time. The minimum time reported using the offset die was 2 minutes and 28 seconds, or 9.6 percent longer than the traditional die. All printers easily achieved their target, consistent with the assumption in Section 3 that, despite some printers' fears, the new die does not increase labor time for printing.

We carried out a survey round in January-March 2014 to all firms. As above, we classify a firm as an adopter if it reports that it is currently using the offset die and has produced more than 1,000 balls cumulatively with it. Of the 10 Group A firms that agreed to participate in the experiment, two firms had already adopted the die at the time we ran the incentive experiment. Of the remaining 8 firms, four firms subsequently adopted. Of the 16 Group B firms, 3 firms had already adopted prior to the invention. None of the remaining 13 firms subsequently adopted.

Table 11 formally assesses the impact of the incentives intervention on adoption rates. All regressions include dummies for the four strata described above. Columns 1-4 include all strata, and Columns 5-8 omit the stratum of firms that had already adopted by Aug. 2013. The first-stage estimates (Columns 1 and 5) indicate, not surprisingly, that assignment to Group A is significantly associated with greater probability of receiving the incentive-payment treatment; that is, we have a strong first stage. The OLS estimates in Columns 2 and 6 are positive and significant, but one might be worried about selection into treatment. However, the reduced-form (intent-to-treat) results and the IV (effect of treatment on the treated) results indicate a positive, significant causal relationship between assignment to Group A or the incentive-payment treatment on adoption.

To check robustness, Table 12 reports results using an alternative indicator of adoption, namely whether the firm purchased its first offset die (beyond the trade-in that we paid for) after Sept. 1, 2013. Of the eight firms that accepted the intervention and had not adopted by Aug. 2013, three subsequently purchased their first offset die.[23] Table 12 shows that the positive causal effect of the incentive-payment treatment on adoption is robust to using this alternative measure of adoption. when we look at ordering a die (rather than usage) as our measure.

It is important to acknowledge that the sample sizes in the incentive-payment experiment are

[22] Among these 10 firms, it was not possible to complete the printer performance test at two firms.

[23] In addition, one large firm that was classified as an adopter, because it was using the offset cutting pattern for table cutting, purchased its first die (beyond the four-panel offset die we originally gave, following the beginning of our intervention.

small. Future versions of this paper will conduct further statistical analysis using techniques that are robust to small samples. The results nevertheless appear to indicate a robust, statistically significant effect of the incentive payment treatment on adoption. Using current use ($> 1,000$ balls), it is striking that fully half of the treated firms that had not previously adopted responded to the treatment. The incentive payments were tiny relative to revenues for the firms, which have mean revenues from soccer-balls of approximately US$100,000 and a median of approximately US$30,000 per month. It seems hard to rationalize such a large response to such a small incentive, unless the incentive is helping to resolve an organizational bottleneck within the firm. That is, the fact that such small payments had a significant effect on adoption decisions suggests that the misalignment of incentives is indeed an important barrier to adoption in this setting.

8 Conclusion

This paper has two basic findings. First, despite the apparent advantages of the technology we invented, a surprisingly small number of firms have taken it up, even among the set of firms that we gave it to. This is consistent with a long tradition of research on technology adoption that has found diffusion to be slow for some technologies, but given the characteristics of our technology — low fixed costs, minimal required changes to other aspects of the production process, limited uncertainty about the cost advantage of the technology — the low adoption rate seems particularly puzzling. Second, with a very small change in the incentives facing key employees in the firm — tiny in monetary terms relative to firms' revenues and the benefits of adoption — we induced a statistically significant increase in adoption. This is consistent with the hypothesis that a misalignment of incentives with the firm — in particular, employees paid piece rate have an incentive to resist adoption of a material-saving technology if it will slow them down — is an important barrier to adoption.

The natural question that arises is why firm owners do not simply change the payment scheme they offer workers. We have considered three possible explanations. One is simply that it does not occur to owners that alternative payment schemes are available. In the same way that owners failed to hit on the best cutting pattern for pentagons, they may have failed to hit on the best organizational arrangement within the firm. A second possible explanation is that there are transaction costs of some sort involved in changing contracts, even implicit ones. Over time, social norms arise around existing contractual practices, and employees may sanction employers who deviate from accepted norms. A third possible explanation is that employees are misinforming owners about the value of the technology and owners are believing them. In this explanation, it is not that owners are unaware of alternative contracts, or that there are costs to adopting them, but that they are not convinced they have good reason to adopt the technology. All three of these explanations are consistent with the information we currently have. In future work we will seek to discriminate between them. The important point for the current paper, however, is that many firms did not in fact change their payment schemes, and this left scope for our very modest intervention to have a large effect on adoption.

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Table 1: Production Costs

	Firm 1 Costs (Rs)	Firm 2 Costs (Rs)
Rexine	50	42.3
Cotton/polyester cloth	30	40
Latex	75	74
Labor for lamination	1.55	2
Labor for cutting	1	2
Labor for printing, matching	8	15
Labor for stitching	45	40
Bladder	52	60
Other (checking, washing, packing, overhead)	17	20
Total	279.55	295.30

Notes: Costs are for two medium-size, middling-quality pilot firms. Exchange rate is approximately 100 Rs/US$1.

Table 2: Firm Characteristics by Quantile

	Mean	Min	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}	Max	N
A. Initial-responder sample									
avg output/month (000s)	32.2	0.8	1.6	3.5	10.0	34.6	83.0	275.0	85
avg employment	90.2	3.3	5.2	7.4	20.0	52.9	235.0	1,700.0	85
avg employment (cutters)	5.8	0.5	1.0	1.0	2.2	5.0	13.0	123.0	85
avg Rs/ball (head cutter)	1.5	1.0	1.1	1.3	1.5	1.6	1.9	2.9	79
avg % promotional (of size 5)	41.4	0.0	2.0	18.8	41.1	62.4	80.0	100.0	85
avg price, size 5 promotional	241.3	152.5	185.0	196.3	227.1	266.8	300.0	575.0	64
avg price, size 5 training	440.0	200.0	275.0	313.8	381.3	488.0	600.0	2,250.0	72
avg profit %, size 5 promo	8.2	2.5	3.9	5.2	8.1	10.2	12.5	20.0	64
avg profit %, size 5 training	8.0	1.6	3.2	4.6	8.5	9.9	12.5	22.2	70
avg % lamination in-house	95.7	31.3	81.3	100.0	100.0	100.0	100.0	100.0	75
% standard design (of size 5)	90.8	0.0	70.0	85.0	100.0	100.0	100.0	100.0	81
age of firm	25.4	2.0	6.0	12.0	19.5	36.5	54.0	108.0	84
CEO experience	17.0	3.0	6.0	9.0	15.5	22.0	28.0	66.0	82
head cutter experience	20.5	2.0	8.0	12.0	18.5	26.5	41.0	46.0	36
head cutter tenure	11.1	0.0	2.0	6.0	9.0	15.0	22.0	46.0	35
B. Full sample									
avg output/month (000s)	34.6	0.0	2.0	4.5	15.0	37.2	86.3	278.6	116
avg employment	103.9	3.3	5.6	8.0	25.0	75.0	230.0	2,180.0	115
avg employment (cutters)	5.4	0.5	1.0	1.2	2.8	5.0	12.4	123.0	114
avg Rs/ball (head cutter)	1.5	1.0	1.0	1.3	1.5	1.6	2.0	3.0	107
avg % promotional (of size 5)	37.0	0.0	0.0	8.3	33.8	55.2	80.0	100.0	114
avg price, size 5 promotional	245.7	150.0	185.0	202.0	235.0	270.0	300.0	575.0	81
avg price, size 5 training	465.0	200.0	286.7	330.0	400.0	506.8	667.9	2,250.0	100
avg profit (%), size 5 promo	8.3	2.5	4.1	5.1	7.7	10.4	13.8	20.0	80
avg profit (%), size 5 training	8.3	1.6	3.4	5.1	8.5	10.0	13.0	22.2	95
avg % lamination in-house	96.2	25.0	85.0	100.0	100.0	100.0	100.0	100.0	104

Notes: Variables beginning with “avg. ...” represent within-firm averages across all rounds for which responses are available. Initial responder sample is firms that responded to baseline survey. Piece rate and prices are in Rupees (exchange rate is approximately 100 Rs/US$1). Age, experience and tenure are in years.

Table 3: Response Rates

	# Firms (initial responders)		
	Tech Drop	Cash Drop	No Drop
A. Initial responders			
smallest	5	3	12
medium-small	6	3	13
medium-large	6	3	13
largest	6	3	12
total	23	12	50
B. Initial non-responders			
active, late response	12	5	14
active, refused all surveys	0	1	15
inactive	7	3	12
total	19	9	41

Table 4: Baseline Balance, Tech-Drop Experiment

	Tech Drop	Cash Drop	No Drop
A. Initial responders			
Output, normal month (000s)	34.18	26.69	41.56
	(11.48)	(12.15)	(9.53)
Output, previous year (000s)	680.17	579.97	763.33
	(220.13)	(225.13)	(232.95)
Employment, normal month	42.26	82.58	92.62
	(13.25)	(47.16)	(35.77)
% size 5	84.61	88.96	82.67
	(5.38)	(4.52)	(3.74)
% promotional (of size 5)	50.12	66.09	59.02
	(7.12)	(11.04)	(5.17)
Age of firm	22.70	29.25	25.76
	(2.25)	(4.88)	(3.09)
CEO experience	16.22	20.42	16.55
	(2.39)	(2.70)	(1.62)
CEO college indicator	0.43	0.27	0.40
	(0.11)	(0.14)	(0.08)
Head cutter experience	17.00	30.33	20.91
	(2.08)	(6.69)	(2.68)
Head cutter tenure	12.20	12.00	10.50
	(2.21)	(5.77)	(2.11)
Share cutters paid piece rate	0.95	0.83	0.89
	(0.05)	(0.11)	(0.05)
Rupees/ball (head cutter)	1.44	1.63	1.37
	(0.14)	(0.21)	(0.10)
N	23	12	50
B. Late responders			
Output, normal month (000s)	27.85	34.80	63.13
	(14.01)	(4.99)	(18.25)
Employment, normal month	67.20	61.00	353.38
	(48.18)	(34.94)	(264.52)
% size 5	68.00	72.22	96.88
	(9.80)	(16.16)	(3.13)
% promotional (of size 5)	31.17	36.11	24.22
	(9.77)	(12.58)	(13.28)
Age of firm	17.40	39.60	35.13
	(3.13)	(16.68)	(5.55)
N	10	5	8

Table 5: Adoption of Technology as of August 2013

	Tech Drop	Cash Drop	No Drop	Total
A. Initial-responder sample				
# ever active firms	23	12	50	85
# ever responded	23	12	50	85
# currently active and ever responded	22	11	46	79
# traded in	15	0	0	15
# ordered new die (beyond trade-in)	1	0	4	5
# received new die (beyond trade-in)	1	0	2	3
# ever used new die (>1000 balls)	4	0	0	4
# currently using new die (>1000 balls)	4	0	0	4
B. Full sample				
# ever active firms	35	18	79	132
# ever responded	35	17	64	116
# currently active and ever responded	32	15	59	106
# traded in	19	0	0	19
# ordered new die (beyond trade-in)	1	0	6	7
# received new die (beyond trade-in)	1	0	4	5
# ever used new die (>1000 balls)	5	0	1	6
# currently using new die (>1000 balls)	5	0	1	6

Table 6: Correlates of Adoption: Scale & Quality Variables (Initial-Responder Sample)

	Dep. var.: indicator for currently using offset die									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
tech drop group	0.18**	0.18**		0.59						0.16**
	(0.08)	(0.08)		(0.51)						(0.07)
cash drop group		-0.00								
		(0.02)								
log avg output/month			0.03	0.04*		0.03				0.06
			(0.03)	(0.02)		(0.03)				(0.04)
log avg output*tech drop				-0.04						
				(0.05)						
share standard (of size 5)					-0.39	-0.38				-0.44
					(0.32)	(0.33)				(0.27)
log avg price, size 5 training							-0.06			-0.19*
							(0.05)			(0.11)
avg share promotional (of size 5)								-0.11		-0.15
								(0.07)		(0.10)
avg profit rate, size 5 training									0.54	0.35
									(0.64)	(0.61)
constant	0.02	0.02	-0.22	-0.29	0.41	0.14	0.40	0.11	0.02	1.15*
	(0.05)	(0.05)	(0.22)	(0.18)	(0.32)	(0.44)	(0.31)	(0.07)	(0.05)	(0.67)
stratum dummies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.22	0.22	0.10	0.25	0.16	0.18	0.09	0.10	0.10	0.36
N	79	79	79	79	75	75	68	79	66	64

Table 7: Correlates of Adoption: Manager & Cutter Characteristics (Initial-Responder Sample)

	Dep. var.: indicator for currently using offset die								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
tech drop group	0.18**								0.17**
	(0.08)								(0.08)
CEO university indicator		0.04							0.01
		(0.07)							(0.05)
CEO experience (/100)			-0.24						-0.11
			(0.17)						(0.20)
age of firm (/100)				-0.06					0.02
				(0.09)					(0.11)
Rs/ball, head cutter					0.11				0.08
					(0.15)				(0.15)
head cutter experience (/100)						-0.03			
						(0.09)			
head cutter tenure (/100)							-0.19		
							(0.23)		
cutter raven's score								-0.01	
								(0.03)	
log avg output/month									0.04
									(0.03)
constant	0.02	0.05	0.11	0.07	-0.10	0.00	0.03	0.03	-0.41
	(0.05)	(0.05)	(0.07)	(0.05)	(0.19)	(0.01)	(0.03)	(0.07)	(0.28)
stratum dummies	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.22	0.09	0.09	0.08	0.11	0.12	0.12	0.18	0.26
N	79	70	77	78	74	33	32	37	64

Table 8: Reasons for Non-Adoption (Technology Group Sample)

firm	no orders to try on	too busy	doubt profitable	waiting for others to prove value	waiting for others to iron out kinks	cutters unwilling	printing problems	other production issues	other
1	2	3					1		
2	2						1		
3	2						1		
4	2						1		
5	2					1			
6	4		3			1	2		
7	3		2			1			
8	3					1	2		
9	3	2				1			
10	1								
11	1								
12	1								
13	3					1	2		
14	3					1	2		
15	2					1			3
16	1								
17	5	3				1	2	4	
18	2	3				1			3

Table 9: Baseline Balance in Wage Contract Experiment

	Group A Wage Contract	Group B No Wage Contract
log avg output/month	9.86	9.31
	(0.41)	(0.29)
log avg employment	3.35	3.23
	(0.38)	(0.25)
log avg price, size 5 promo	5.40	5.45
	(0.02)	(0.07)
log avg price, size 5 training	6.00	5.93
	(0.06)	(0.06)
avg % promotional (of size 5)	34.90	32.04
	(6.20)	(7.26)
avg Rs/ball, head cutter	1.45	1.63
	(0.10)	(0.15)
CEO university indicator	0.56	0.36
	(0.18)	(0.15)
CEO experience	15.50	16.50
	(3.60)	(3.60)
age of firm	24.53	20.60
	(2.83)	(2.28)
N	15	16

Table 10: "Test" Results

firm	1	2	3	4	5	6	7	8	9	10
time	2:52	2:40	3:03	3:02	2:59	2:28	2:25	2:45	2:30	2:50
die size	43.5	43.75	44	44	43.5	43.5	43.5	43.5	44	43.5
# pentagons	270	272	273	272	282	279	279	272	272	267

Table 11: Incentive-Payment Experiment Results (Current Use as Outcome)

	Dep. var.: currently using offset die and produced $> 1,000$ balls							
	All Strata				Initial Non-Adopters			
	First Stage	OLS	Reduced Form (ITT)	IV (TOT)	First Stage	OLS	Reduced Form (ITT)	IV (TOT)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
rec'd treatment		0.39**		0.38**		0.48**		0.50**
		(0.16)		(0.15)		(0.19)		(0.19)
assigned to group A	0.68***		0.26**		0.62***		0.31**	
	(0.12)		(0.11)		(0.14)		(0.13)	
stratum dummies	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.57	0.66	0.59	0.66	0.50	0.43	0.26	0.43
N	31	31	31	31	26	26	26	26

Table 12: Incentive-Payment Experiment Results (Die Purchase as Outcome)

	Dep. var.: purchased first offset die (beyond trade-in) after Sept. 1, 2013							
	All Strata				Initial Non-Adopters			
	First Stage	OLS	Reduced Form (ITT)	IV (TOT)	First Stage	OLS	Reduced Form (ITT)	IV (TOT)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
rec'd treatment		0.42**		0.40**		0.40**		0.38**
		(0.15)		(0.16)		(0.16)		(0.17)
assigned to group A	0.68***		0.27**		0.62***		0.23*	
	(0.12)		(0.12)		(0.14)		(0.12)	
stratum dummies	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.57	0.40	0.24	0.40	0.50	0.40	0.22	0.40
N	31	31	31	31	26	26	26	26

Figure 1: U.S. Imports of Inflatable Soccer Balls

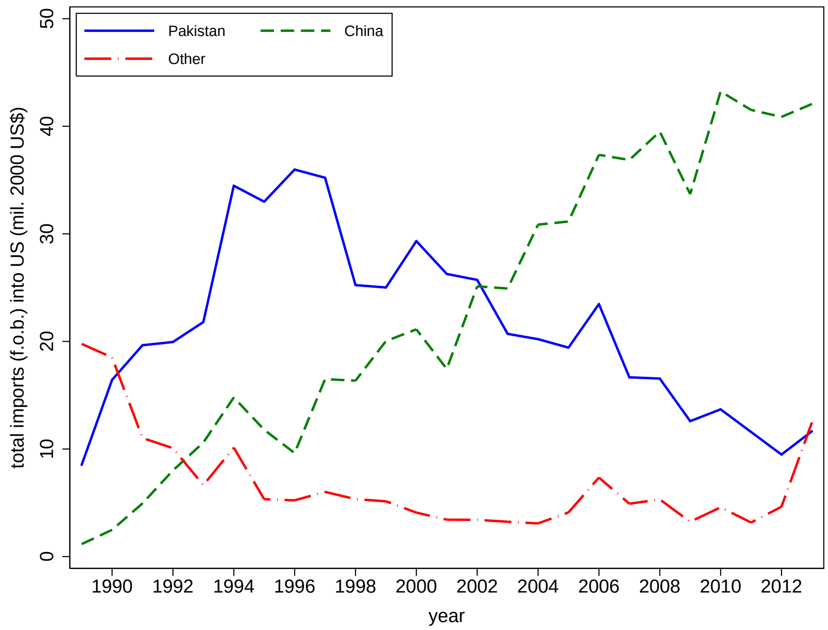


Figure 2: “Buckyball” Design

Figure 3: Making the Laminated Sheet (Step 1)

Figure 4: Cutting the Laminated Sheet (Step 2)

Figure 5: Printing the Designs (Step 3)

Figure 6: Stitching (Step 4)

Figure 7: Traditional 2-Hexagon and 2-Pentagon Dies

Figure 8: Laminated Sheet Wastage from Cutting Hexagons

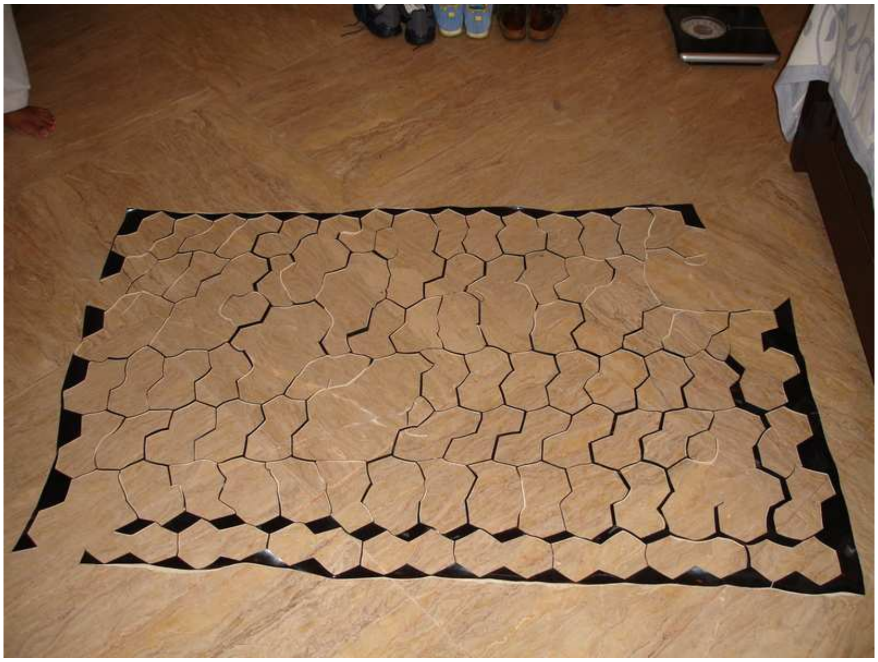


Figure 9: Laminated Sheet Wastage from Cutting Pentagons

Figure 10: Blueprint for “Offset” Four-Pentagon Die

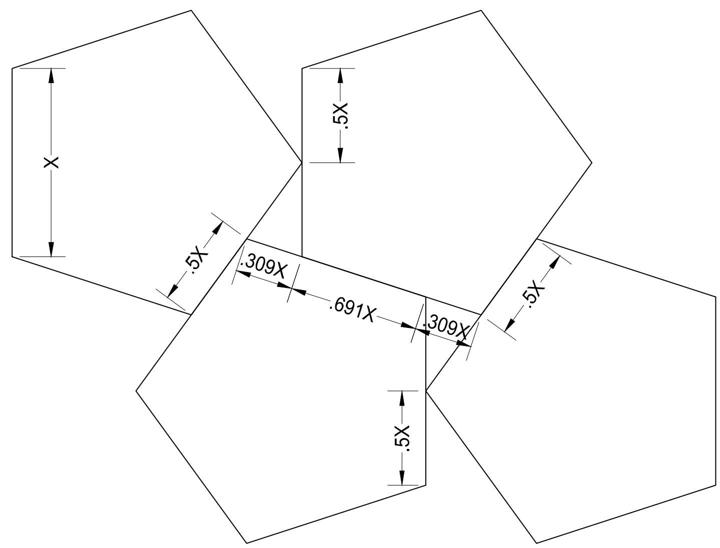


Figure 11: Cutting Pattern for “Offset” Four-Pentagon Die

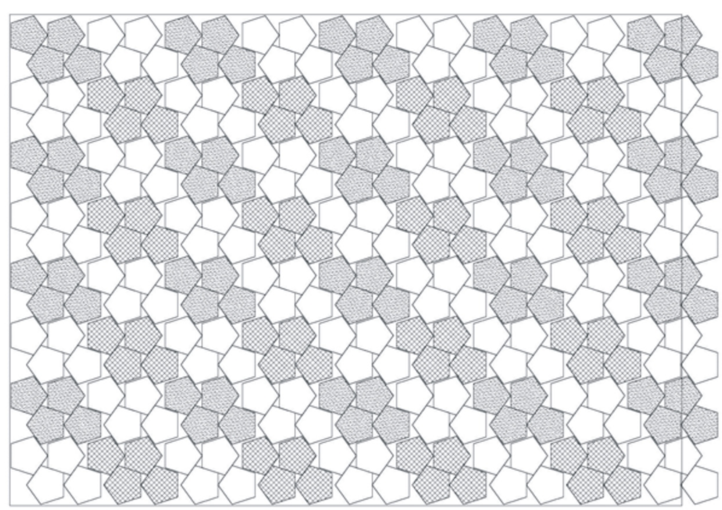


Figure 12: The “Offset” Four-Pentagon Die

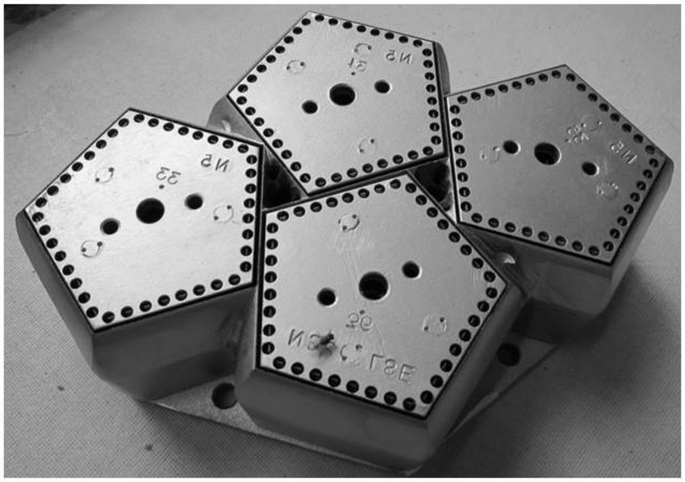
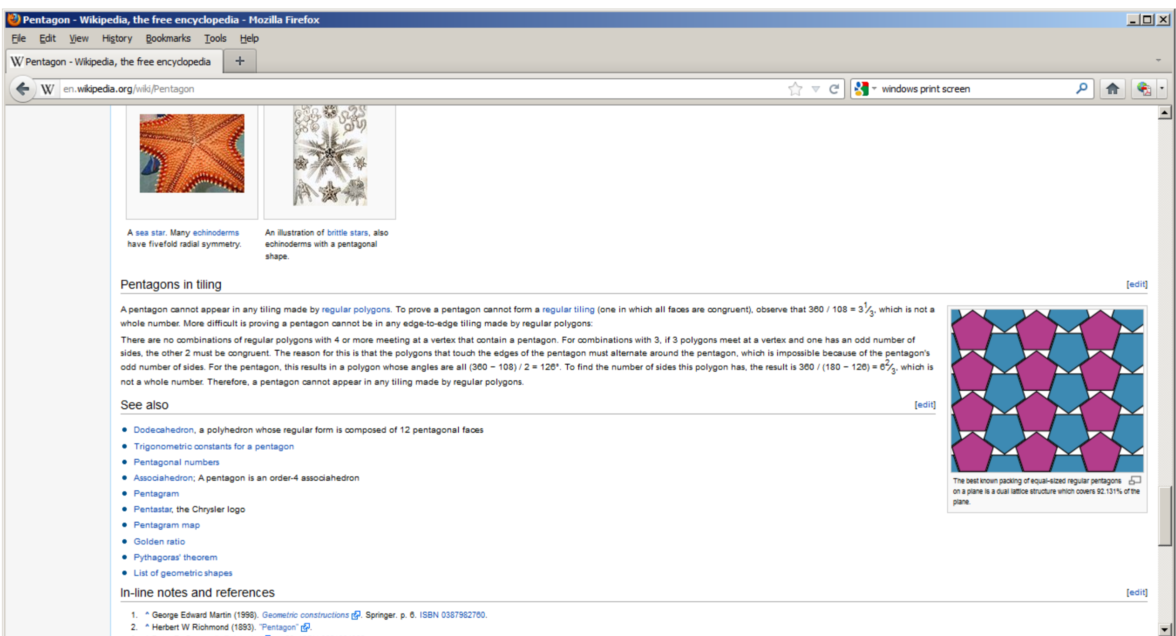


Figure 13: Wikipedia “Pentagon” Page



Note: Accessed April 29, 2012.

Figure 14: Adoption of Offset Dies by Firm Z

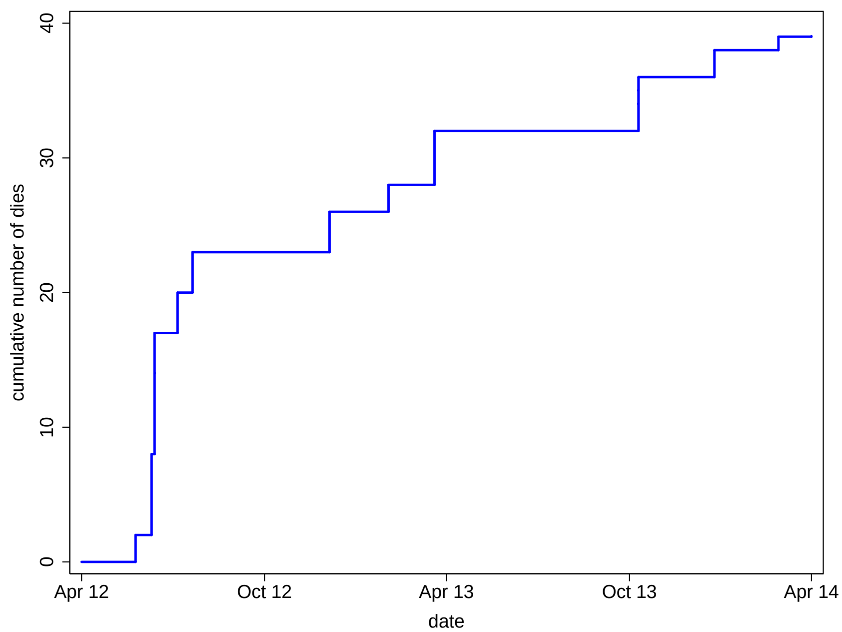


Table A.1: Means by Firm Size Bin

	Firm Size Bins				Late
	1	2	3	4	Responders
A. Initial-responder sample					
avg output/month (000s)	5.43	6.18	24.49	93.08	
avg employment	11.68	13.29	53.07	284.43	
avg employment (cutters)	1.25	1.79	3.84	16.36	
cutters paid piece rate indicator	0.90	1.00	0.91	0.79	
avg Rs/ball (head cutter)	1.53	1.54	1.51	1.38	
avg % promotional (of size 5)	49.44	51.40	34.47	30.61	
avg price, size 5 promotional	239.57	223.76	249.23	254.26	
avg price, size 5 training	387.09	329.23	442.18	617.36	
avg profit %, size 5 promo	6.15	7.20	9.58	10.16	
avg profit %, size 5 training	6.95	7.00	8.25	9.86	
avg % lamination in-house	90.64	92.74	99.77	99.82	
% standard design (of size 5)	89.00	94.43	90.43	89.21	
age of firm	16.95	20.09	24.67	39.81	
CEO experience	19.00	16.55	15.75	16.85	
head cutter experience	13.83	20.44	26.82	17.60	
head cutter tenure	12.50	7.33	13.55	11.00	
N	20	22	22	21	
A. Full sample					
avg output/month (000s)	5.43	6.18	24.49	93.08	41.23
avg employment	11.68	13.29	53.07	284.43	142.65
avg employment (cutters)	1.25	1.79	3.84	16.36	4.42
avg Rs/ball (head cutter)	1.53	1.54	1.51	1.38	1.61
avg % promotional (of size 5)	49.44	51.40	34.47	30.61	23.93
avg price, size 5 promotional	239.57	223.76	249.23	254.26	262.34
avg price, size 5 training	387.09	329.23	442.18	617.36	529.49
avg profit %, size 5 promo	6.15	7.20	9.58	10.16	8.68
avg profit %, size 5 training	6.95	7.00	8.25	9.86	9.29
avg % lamination in-house	90.64	92.74	99.77	99.82	97.41
N	20	22	22	21	31

Notes: Size bins are defined as quartiles of output in a normal month from baseline survey. Same bins are used as strata in technology-drop experiment. Late responders (i.e. who did not respond at baseline) could not be assigned to a size bin by this definition. Piece rate and prices are in Rupees (exchange rate is approximately 100 Rs/US$1). Age, experience and tenure are in years.