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# 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, that was conditional on them demonstrating 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 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. Comin and Hobijn (2010) study 15 major technologies and find that countries adopt new technologies 45 years after their invention, on average.[4]

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 (Tybout, 2000). It is rare to be able to observe firms' technology use directly, even after the fact. It is rarer still to have direct measures of either 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 a cluster of soccer-ball producers in Sialkot, Pakistan, that a conflict of interest between employees and owners within firms is an important barrier to adoption. The cluster produces 30 million soccer balls a year, or about 40 percent of world production, including match balls for the 2014 World Cup, and about 70 percent of world hand-stitched production (Wright, 2010; Houreld, 2014). 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 technology we focus on is immediately applicable at a large enough number of firms to conduct statistical inference.

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.

[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).

[4]Grübler (1991) finds that the majority of 265 diffusion processes in the United States take 15-30 years to spread. See also the surveys by Stoneman (2002), Hall and Khan (2003) and Hall (2005) for more examples.

The most common soccer-ball design combines 20 hexagonal and 12 pentagonal panels (see Figure 1). 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 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 new die requires minimal adjustments to other aspects of the production process. Crucially, we observe adoption of the new die very accurately, in contrast to studies that infer technology adoption from changes in estimated productivity such as those reviewed in Syverson (2011).

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. Anecdotal evidence from a number of firms we visited suggested that workers were resisting the new die in a variety of ways, including by misinforming owners about the productivity benefit of the 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, the anecdotes from firm visits, and the pay scheme of 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, including by misinforming the owners about the value of the technology. We formalize this intuition in a simple model of strategic communication between an imperfectly informed principal and a perfectly informed agent within a firm, which captures many important features of our setting. When standard piece-rate contracts are used, we show that there is an equilibrium in which the agent misinforms the principal about the benefits of the new technology and the principal is influenced by the agent not to adopt it. We also show that a relatively simple modification to the labor contract, conditioning the wage contract on the ex-post-revealed characteristics of the technology, induces the agent to truthfully reveal the technology and the principal to adopt it.

To investigate these hypotheses, we designed and implemented a new 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 one-time bonus payments were small relative both to revenues from soccer-ball sales for the firms, which have a mean of approximately US$146,000 and a median of approximately US$58,000 per month, and to the (variable) cost reductions from adopting of our technology, which we estimate to be approximately US$1,740 per month at the mean or US$493 per month at the median.

The experiment was run on a total of 31 firms, 15 randomized into group A and 16 into group B. Of the 13 group-A firms that had not already adopted the new die, 8 accepted the incentive-payment intervention, and 5 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, with the probability of adoption increasing by 0.32 in the most conservative intent-to-treat specification. Our results are robust to using permutation tests that are robust to small sample sizes. 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.

A natural question that arises is why the firms themselves did not adjust their payment schemes to incentivize their employees to adopt the technology. Our model suggests two possible explanations. The first is that owners simply did not realize that such an alternative payment scheme was possible, just as the technical innovation had not occurred to them. The second is that there is some sort of transaction cost involved in changing payment schemes, a possibility that we discuss in Section 6 below. Firms will weigh the perceived benefits of the technology against the transaction cost; if firms have a low prior that the technology is beneficial, they may not be willing to pay the cost of modifying employment contracts. The hypotheses that firms were unaware of the alternative payment scheme and that implementing a new scheme is perceived to be too costly to be worthwhile have similar observable implications and we are not able to separate them with our second experiment. 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. Bloom and Van Reenen (2007), Bloom and Van Reenen (2010) and the aforementioned Bloom et al. (2013) all suggest a lack of competition may be responsible to the failure to adopt beneficial management practices. Another branch of literature emphasizes that new technologies often require many changes in complementary technologies, which often take time to implement (Rosenberg, 1982; David, 1990; Bresnahan and Trajtenberg, 1995). In our setting, unions are absent, firms sell almost all output on international export markets that appear to be reasonably competitive, and our technology requires extremely modest changes to other aspects of production, so it does not appear that these common explanations are directly applicable. We view our focus on intra-organizational barriers as complementary to these literatures.

The theoretical model we develop draws on ideas from two strands of theoretical literature: the literature on strategic communication following Crawford and Sobel (1982), reviewed by Farrell and Rabin (1996) and Sobel (2013), and the voluminous literature on principal-agent models of the employment relationship reviewed by Lazear and Oyer (2013) and Gibbons and Roberts (2013). There is a smaller literature that combines elements of the two strands, for instance Lazear (1986), Gibbons (1987), Dearden et al. (1990), Carmichael and MacLeod (2000), Dessein (2002) and Krishna and Morgan (2008). Lazear (1986) and Gibbons (1987) formalize the argument that workers paid piece rates may hide information about productivity improvements from their employers, to prevent employers from reducing rates. Carmichael and MacLeod (2000) explore the contexts in which firms will commit to fixing piece rates in order to alleviate these "ratchet" effects. Holmstrom and Milgrom (1991) show that high-powered incentives such as piece rates may induce employees to focus too much on the incentivized task to the detriment of other tasks, which could include reporting accurately on the value of a technology. Our study supports the argument of Milgrom and Roberts (1995) that to be effective piece rates may need to be combined with other incentives, in our case higher pay conditional on adopting the new technology. In related empirical work, Freeman and Kleiner (2005) provide case-study evidence from an American shoe company whose shift away from piece rates arguably helped it to increase productivity.[5]

Our paper is related to an active literature on technology adoption in agriculture in developing countries (e.g. Foster and Rosenzweig (1995), Munshi (2004), Bandiera and Rasul (2006), Conley and Udry (2010), Duflo, Kremer, and Robinson (2011), Suri (2011), and Hanna, Mullainathan, and Schwartzstein (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 in that they involve issues of organizational conflict that do not arise when the decision-makers are individual farmers.[6] Our setting also differs in that risk arguably plays a less important role than in agriculture, both because there is a lower degree of production risk (which we would expect to make the inference problem about the value of a technology easier) and because our factory owners are presumably less risk-averse than small-holder farmers.

Our paper is also related to the "insider econometrics" literature on management practices and productivity reviewed by Ichniowski and Shaw (2013). Our study shares with this literature the focus on the technology and management choices of firms in a single industry, but while the insider-econometrics literature has tended to focus on careful documentation of differences across firms in cross-section, we examine the within-firm responses of firms to randomized shocks to their technological knowledge and organizational practices. In this literature, our paper is perhaps most closely related to the above-mentioned experimental study by Bloom et al. (2013) of the effect of consulting services on productivity in the Indian textile industry. In addition to emphasizing the role of the lack of competition, Bloom et al. suggest that informational constraints are an important factor leading firms not to adopt simple, apparently beneficial, elsewhere widespread, practices. Our study investigates how conflicts of interest within firms can impede the flow of information to managers and provides a possible microeconomic rationale for the importance of such informational constraints, and in this sense we view our work as complementary.

[5] A recent experimental study by Khwaja et al. (2014) focuses on a public bureaucracy in the Punjab property tax department, but focuses on a similar issue: the effect of altering wage contracts on employee performance and resistance to reform.

[6] A recent paper by Beaman et al. (2014) studies the effect of informational interventions on the change-holding behavior of Kenyan retail microenterprises, which are also individual decision-makers.

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 qualitative evidence on organizational barriers to adoption and presents our model of strategic communication in a principal-agent context. 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 province of Punjab. The origins of the soccer-ball cluster date to British colonial rule.[7] 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's new ball 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 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 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 2.) 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 (with the balls the 2014 FIFA World Cup being made in both China and Sialkot). 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

[7] This summary of the history of the sector draws on an undated, self-published book by a member of a soccer-ball-producing family (Sandal, undated).

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 Description

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 1), often referred to as the "buckyball" design.[8] There are four stages of production. In the first stage, shown in Figure 3, layers of cloth (cotton and/or polyester) are glued to an artificial leather called rexine 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 46 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.[9] 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 substantial share of their production. A few firms

[8] The buckyball resembles a geodesic dome designed by R. Buckminster Fuller.

[9] We use "he" since all of the cutters (as well as the printers and owners) we have encountered in the industry have been men.

in the cluster have implemented machine-stitching, but this has little effect on 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, with the two panels sharing an entire edge. (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 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 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.) Through an intermediary, 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 is well known to mathematicians. For example, the pattern appeared in a 1990 paper in the journal *Discrete & Computational Geometry* (Kuperberg and Kuperberg, 1990), and also appears, conveniently enough, on the Wikipedia "Pentagon" page.[10] (See Figure 13.)[11]

The pentagons in the new die are offset, with the two leftmost pentagons sharing half of an

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

[11] One might wonder whether firms in Sialkot 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 produce for Adidas, we suspect that they were aware of the offset cutting pattern before we arrived. What is clear, however, is that neither the offset cutting pattern nor the offset die were in any other firm we visited as of the beginning of our experiment in May 2012.

edge, unlike in 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

We now turn to a calculation of the benefits and costs of using the new offset die. In order to quantify the various benefit and cost components we draw on several rounds of survey data that we describe in more detail in Section 4 below.

#### 3.2.1 Reductions in wastage

We start by comparing the number of pentagons using the traditional die with the number using the offset die. The dimensions of pentagons and hexagons vary slightly across firms, even for balls of a given official size (e.g. size 5, the standard size for adults). The most commonly used pentagons have edge-length 43.5 mm, 43.75 mm, 44 mm or 44.25 mm after stitching. The first two columns of Table 1 report the means and standard deviations of the numbers of pentagons per sheet for each size, using a standard (39 in. by 54 in.) sheet of rexine. Column 1 uses information from owner self-reports; we elicited the information in more than one round, and here we pool observations across rounds. Column 2 uses information from direct observation by our survey team, during the initial implementation of our first experiment. In order to facilitate comparison across die sizes, we have multiplied each size-specific measure by the ratio of means for size 44 mm and the corresponding size, and then averaged the rescaled measure across sizes. The rescaled measure, reported in the row labeled "rescaled," provides an estimate of the number of pentagons per sheet the firm would obtain if it used a size 44 mm die. We see that the owner reports and direct observations correspond reasonably closely, with owners slightly overestimating pentagons per sheet relative to our observations. Both measures suggest that cutters obtain approximately 250 pentagons per sheet using the traditional die.

Using the new offset die and cutting 44 mm pentagons, it is possible to achieve 272 pentagons, as illustrated in Figure 11.[12] For smaller 43.5 mm pentagons, it is possible to achieve 280 pentagons. Columns 3-4 of Table 1 report the means and standard deviations of pentagons per sheet using the offset die. As discussed in more detail below, relatively few firms have adopted the offset die, and therefore we have many fewer observations. But even keeping in mind this caveat, we can say with a high level of confidence that more pentagons can be obtained per

[12] If a cutter reduces the margin between cuts, or if the rexine sheet is slightly larger than 39 in. by 54 in., it is possible to cut more than 272 with a size 44 mm die.

sheet using the offset die. The directly observed mean is approximately 272, and the standard errors indicate that difference from the mean for the traditional die (either owner reports or direct observations) is significant at greater than the 99 percent level.

### 3.2.2 Cost savings from reduced wastage

In order to convert these reductions in wastage into cost savings we need to know the proportion of costs that materials and cutting labor account for. Table 2 provides a cost breakdown for a promotional ball obtained from our baseline survey.[13] The table shows that the laminated sheet (which combines the rexine and cotton/polyester cloth using the latex glue) accounts for roughly half of the unit cost of production: 46 percent on average. The inflatable bladder is the second most important material input, accounting for 21 percent of the unit cost. Labor of all types accounts for 28 percent, but labor for cutting makes up less than 1 percent of the unit cost. Overhead accounts for the remaining 5 percent of the cost of a ball. In the second column, we report the input cost in rupees; the mean cost of a two-layer promotional ball is Rs 211. (The exchange rate has varied from 90 Rs/US$ to 105 Rs/US$ over the period of the study. To make calculations easy, we will use an exchange rate of 100 Rs/US$ hereafter.)

The cost savings from the offset die vary across firms, depending in part of the type of rexine used and the number of layers of cloth glued to it, which themselves depend on a firm's mix of promotional balls and more expensive training balls. How long it takes firms to recoup the fixed costs of adoption also varies across firms, depending in part on total production and the cutters employed by the firm.[14] In Table 3, we present estimates of the distribution of the benefits and costs of adopting the offset die for firms. Not all firms were willing to provide a cost breakdown by input, and only a subset of firms have adopted the offset die. In order to compute the distribution of costs of benefits across all firms, we adopt a hot-deck imputation procedure that replaces a firm's missing value for a particular cost component with a draw from the empirical distribution within the firm's stratum, and then compute the distribution of benefits.[15] We repeat this procedure 1,000 times and report the mean values at various percentiles of the distribution as well the corresponding standard errors.

In row 1 of Table 3, we report the distribution of the percentage reduction in rexine waste from the offset die. This is the product of (a) the percentage decline in rexine waste in cutting pentagons from adopting the offset die, (b) the share of pentagons in total rexine costs (about

[13]In the baseline survey, firms were asked for a cost breakdown of a size-5 promotional ball with two layers (one cotton and one polyester), the rexine they most commonly use on a two-layer size-5 promotional ball, a glue comprised of 50 percent latex and 50 percent chemical substitute (a cheaper alternative), and a 60-65 gram inflatable latex bladder.

[14]Some firms have multiple cutters each of whom may require his own die.

[15]As discussed below, firms were stratified according to total monthly ball product at baseline. One stratum, the late responder sample we describe in detail below, was not asked the rexine share of cost at baseline. We therefore draw the rexine shares for these firms from the empirical distribution that pools the other strata.

33 percent because a standard ball uses more hexagons than pentagons and each hexagon has a larger surface area than each pentagon), and (c) the share of rexine in unit costs. The reduction in rexine waste is 7.93 percent at the median and ranges from 4.39 percent at the 10th percentile to 13.43 percent at the 90th percentile. Combining the reduction in rexine waste with the rexine share of unit costs (whose distribution is reported in row 2) and multiplying by 33 percent yields the percentage reduction in variable material costs reported in row 3. The reduction in variable material costs is 1.10 percent at the median and ranges from .60 percent at the 10th percentile to 1.94 at the 90th percentile.[16]

The new die requires the cutters to be more careful in the placement of the die while cutting. A conservative estimate of the increase in labor time for cutters is 50 percent. (Below we discuss why this number is conservative.). The fourth row of Table 3 reports the distribution of the cutter's wage as a share of unit costs across firms. As noted earlier, the cutter's share of cost is quite low.[17] Multiplying the cutter share by 33 percent (assuming that pentagons take up one third of cutting time, equivalent to their share of rexine cost) and then by 50 percent (an estimate of the increase in labor time) yields the percentage increase in variable labor costs from adopting the offset die (row 5).

Although the increase in cutting time is potentially large, the cutter's share of cost is sufficiently low that the variable labor cost increase is very small. Row 6 reports the *net* variable cost reduction as the difference between the variable materials cost reduction and the variable labor cost increase. The net variable cost reduction is 1.02 percent at the median, and ranges from .52 percent at the 10th percentile to 1.87 percent at the 90th percentile. Although these numbers are small in absolute terms, the cost reductions are not trivial given the low profit margins in this competitive industry. Row 7 shows the ratio of the net variable cost reductions to average profits;[18] the mean and median ratios are 15.45 percent and 12.34 percent, respectively, and the ratio ranges from 5.27 percent at the 10th percentile to 28.98 percent at the 90th percentile.

If we multiply the net variable cost reduction by total monthly output, we obtain the total monthly savings, in rupees, from adopting the offset die (row 8). The large variation in output across firms induces a high degree of heterogeneity in total monthly cost savings. The mean

[16] Note that because a firm at the 10th percentile of rexine waste reduction is not necessarily the same firm at the 10th percentile of rexine as a share of cost, the numbers are not multiplicative across rows within a percentile. Likewise, the mean of the variable material cost reduction is not multiplicative across rows because of potential correlations between rexine as a share of costs and rexine waste reduction.

[17] The cutter wage as a share of costs reported here is lower than in Table 2. This is because Table 2 reports input components as a share of the cost of a promotional ball. In Table 3, we explicitly account for firms' product mix across promotional and training/match balls. To get the firm's average ball cost, we divide its reported price of a promotional ball by one plus the reported promotional-ball profit margin. We perform the analogous procedure for training balls, which are more expensive to make. We then construct the firm's weighted-average unit cost using its reported fraction of total production on promotional balls. The cutter share of cost is then calculated as the per ball payment divided by this weighted-average unit cost.

[18] The firm's profit margin is a weighted average of its reported profit margin on promotional and training balls where the weights are the share of each ball type in total production.

and median monthly cost savings are Rs 174,120 ($1,741) and Rs 49,380 ($493), respectively, and this ranges from Rs 4,460 ($44) at the 10th percentile to Rs 475,010 ($4,750) at the 90th percentile.

#### 3.2.3 Net benefits of adoption

These reductions in variable cost must be compared with the fixed costs of adopting the offset die. There are a number of such costs, 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 of firms that do not have in-house screenmaking capabilities, a new screen costs Rs 200 ($2) to buy from an outside screenmaker. We note that new screens must anyway be made for any new order but we include them to be conservative. Third, a subset of firms use a hole-punching machine, a device that punches holes at the edges of panels to facilitate sewing. These machines also use dies. It is always possible to use a single-pentagon punching die, but there is benefit in terms of speed to using a two-pentagon punching die in these machines. A two-pentagon punching die 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).

The final two rows of Table 3 report the distribution of the number of days needed to recover these fixed costs of adoption. For this calculation, it is important to account for the fact that firms often have multiple cutters, each of whom may have his own pentagon die (and potentially need a separate screen and punch). We divide monthly firm output by the number of cutters to calculate output per cutter per month and hence the cost savings per cutter per month. Dividing our conservative estimate of (per cutter) fixed costs by cost savings per cutter gives the number of days needed to recoup the fixed costs, reported in row 9. The median firm can recover all fixed costs within 37 days; this ranges from 9 days at the 10th percentile to 194 days at the 90th percentile (generally firms who produce very few balls). The final row reports the distribution of days to recover fixed costs that exclude the cost of purchasing the die; this column is relevant for the tech-drop firms, to which we gave dies at no cost. In this scenario, the median days to recover fixed costs is only 19 days.

#### 3.2.4 Advantages of the technology for studying adoption

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 obtained reports of sales of the offset dies from the six diemakers operating in Sialkot. Third, as detailed above, the new die requires minimal changes to other aspects of production. Fourth, the new technology is easy to disseminate. It can be explained and demonstrated in thirty minutes. 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. In 75 percent of firms, the fixed costs of adoption could be paid off in less then three months. For half of the firms, it would take less than 5 weeks. For the subset of firms to which we gave dies, the corresponding numbers are 5 weeks and 3 weeks.

## 4 Data 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 laminated sheets. 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.

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.[19] 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 and 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 well as information pertinent to the adoption of the new cutting technology.

Table 4 presents summary statistics on various firm characteristics, including means and

[19]In 1995, there was a child-labor scandal in the industry. Firm owners were initially quite distrustful of us in part for that reason.

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. As firms' responses are often noisy, where possible we have taken within-firm averages across all survey rounds for which we have responses (indicated by "avg. ..." at the beginning of variable names in the table). Focusing on the initial-responder sample, 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).[20] Profit rates are generally low, approximately 8 percent at the median and 12.5 percent at the 90th percentile. The corresponding firm size and profit margins in the full sample (Panel B) are slightly larger indicating that the late responders are larger than the initial responders. 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.[21] Table A.1 in the appendix shows how the same variables very across firm-size bins for both the initial-responder and full samples.

# 5 Experiment 1: The Technology-Drop Experiment

In this section we briefly describe our first experiment, the technology-drop experiment. Additional details are provided in Atkin et al. (2014), which focuses on spillovers in technology adoption. For the purposes of the current paper, the first experiment mainly serves to provide evidence of low adoption, a puzzle we investigate using the second experimental intervention motivated in Section 6 and described in Section 7.

## 5.1 Experimental Design

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. We included the cash-drop group in order to shed light

[20] 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.

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

on the possible role of credit constraints in the technology-adoption decision. The top panel of Table 5 summarizes the distribution of firms across groups for the initial-responder sample. Approximately 27 percent of firms were assigned to the tech-drop group and 13.5 percent to the cash-drop group.[22] These allocations were chosen with the aim of ensuring we had a sufficient number of firms outside the tech-drop group to examine the channels through which spillovers occur. In addition, because we were interested in tracking all firms in the cluster, we treated initial non-responders as a separate stratum and divided them 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 5 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 than 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. In our second experiment, where we focus only on active tech-drop firms, all of which responded, this distinction will be irrelevant.

We began the technology-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 (combining Figures 10 and 11). 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 two-panel version of the offset die of the same size if they chose to. Of the 35 tech-drop firms, 19 took up the trade-in offer. All of these chose to trade in for the two-panel version of the offset die which was easier to maneuver. The cash group was given cash equal to the price we paid for each four-pentagon offset die, Rs 30,000 (US$300), but no information about the new die. Firms in the no-drop group were given nothing.

To examine baseline balance, Panel A of Table 6 reports the mean of various firm characteristics across the tech-drop, cash-drop and no-drop groups for the initial-responder sample.

[22] There were 88 firms with 22 in each stratum at the moment of assignment. In each stratum, 6 firms were assigned to the tech-drop group, 3 to cash-drop group and 13 to the no-drop group. Three firms that responded to our baseline survey subsequently either shut down or were revealed not to be firms by our definition, leaving 85 firms.

We find no significant differences across groups.[23] It appears that the randomization generated exogenous variation in initial exposure among the initial responders. Panel B of Table 6 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 results that include 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 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 firms, 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 7 reports adoption rates 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 firms that were both active and responded to our surveys. 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 and sixth rows report the number of firms that ordered and that received dies (beyond the one trade-in offered to tech-drop firms). The numbers are

[23] 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.

modest: in the full sample, one tech-drop firm and six no-drop firms made an additional order. (One diemaker was slow in delivering dies and firms canceled their orders, 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 7 report the number of firms who had ever adopted the offset die and the number who were currently using the die in August 2013, respectively.

In the full sample, there were five adopters in the tech-drop group and one in the no-drop group as of August 2013.[24] (In the initial-responder sample, the corresponding numbers are four and zero.) These numbers 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.

### 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 August 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. Additionally, given the low rates of adoption, we have limited variation to work with.

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, one 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,[25] 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 the firms' 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

[24] 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.

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

die that we were not aware of. Beyond our arguments about the mathematical superiority of our cutting design and our cost-benefit breakdown, 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 August 2013, and has ordered 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. The firm had abundant time to evaluate the efficacy of the offset die and subsequently placed multiple additional orders. It would be hard to rationalize this behavior if the offset die were not profitable for this firm.

A third hypothesis is that the fixed costs are larger than we have portrayed them to be in our discussion in Section 3 (where we estimated that the majority of tech drop firms would cover their fixed costs in less than 3 weeks, and the majority of non-tech-drop firms in less than 5 weeks). In this scenario, fewer firms would find it profitable to adopt and the firms for which it would be worth paying the fixed cost would be those that produce at a sufficient scale or who specialize in higher quality balls. (Firms that produce higher quality balls use higher-quality imported rexine and so may have stronger incentives to adopt since rexine accounts for a larger portion of their unit costs.) To examine these hypotheses, Table 8 estimates a linear probability model relating adoption to firm characteristics pertaining to scale and quality. Given the low levels of adoption, we are unable to infer correlates of adoption with precision. That said, 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 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 fourth 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 fifth, related hypothesis is that adoption depends on worker skill, especially of the cutter. Table 9 reports results of linear models with several measures of manager and worker characteristics as covariates. There is no significant relationship between manager education or experience, age of the firm, head cutter experience, tenure, or score on a Raven's IQ-type test.

There is also no significant relationship with whether cutters are paid piece rate or the level of piece rate. The one variable that appears marginally significant is the number of pentagons per sheet achieved with the traditional die (rescaled as in Table 1 discussed above), which can be interpreted as a direct measure of the skill of the cutter. But this variable is not robust to the simultaneous inclusion of other firm characteristics in Column 11.

Given the small number of adopters as of August 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

## 6.1 Qualitative evidence

Puzzled by the lack of adoption, in the March-April 2013 survey round we added a question asking tech-drop group firms to rank the reasons for why they had not adopted the new technology, providing nine options (including an "other" category).[26] Table 10 reports the responses 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 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 firms. One notable piece of evidence is from the firm we have called Firm Z, the large adopter from the no-drop group. As noted above, more than 90 percent of firms in Sialkot pay piece rates to their cutters. Firm Z is an exception: in part because of pressure from an international client, for several years the firm has instead paid a guaranteed monthly salary supplemented by a performance bonus, to guarantee that all workers earn at least the legal minimum wage in Pakistan. While we do not find a statistically significant relationship on average between

[26] 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 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].

whether a firm pays a piece rate and adoption (see Table 9), we view the fact that this large early adopter uses an uncommon pay scheme as quite suggestive.

We also feel that it is useful to quote at some length from reports to us from our own survey team.[27] To be clear, the following reports are from factory visits during the second experiment, which is described in Section 7 below, and we are distorting the chronology of events by reporting them here, but we feel that they are useful to capture the flavor of the owner-cutter interactions that we seek to capture in the theoretical model. As mentioned above and described in more detail below, in our second experiment we offered one cutter in each firm (conditional on the approval of the owner) a lump-sum US$150 (15,000 Rupees, denoted PKR) incentive payment to demonstrate competence in using the offset die.[28] The following excerpts are all from firms in the group assigned to treatment for the second experiment.

In one firm, the owner told the survey team that he was willing to participate in the experiment but that the team should ask the cutter whether he wanted to participate. The report continues:

> *[The cutter] explained that the owner will not compensate him for the extra panels he will get out of each sheet. He said that the incentive offer of PKR 15,000 is not worth all the tensions in future.*

It appears in this case that the cutter is seeking to withhold information about the new die in order to avoid a future decline in the effective wage. The firm was not treated.

In another firm, the owner, who had agreed to participate in the treatment, was skeptical when the enumerators returned to test the competence of the cutter with the new technology. Our survey team writes,

> *[The owner] told us that the firm is getting only 2 to 4 extra pentagon panels by using our offset panel... The owner thinks that the cost savings are not large enough to adopt the offset die... He allowed us to time the cutter.*

The team then continued to the cutting room without the owner.

> *On entering the cutting area, we saw the cutter practicing with our offset die... We tested the cutter... He got 279 pentagon pieces in 2 minutes 32 seconds... The cutter privately told us that he can get 10 to 12 pieces extra by using our offset die.*

The owner then arrived in the cutting area.

> *We informed the owner about the cutter's performance. The owner asked the cutter how many more pieces he can get by using the offset die. The cutter replied, "only 2 to 4 extra panels."*

[27]The team included our research assistant, Tariq Raza, who wrote the reports, and the staff of the RCONS: Research Consultants survey firm.

[28]We also offered one printer per firm an incentive payment of US$120, as described below.

It appears that the cutter had been misinforming the owner. But the cutter was not willing to risk dissembling in the cutting process itself.

> *The owner asked the cutter to cut a sheet in front of him. The cutter got 275 pieces in 2 minutes 25 seconds. The owner looked satisfied by the cutter's speed... The owner requested us to experiment with volleyball dies.*

This firm subsequently adopted the offset die.

In a third firm, the owner reported that he had modified the wage he pays to his cutter to make up for the slower speed of the new die. Our team writes,

> *[The owner] said that it takes 1 hour for his cutter to cut 25 sheets with the conventional die. With the offset die it takes his cutter 15 mins more to cut 25 sheets for which he pays him pkr 100 extra for the day which is not a big deal.*

This firm has generally not been cooperative in our survey, and we have not been able to verify that the firm has produced more than 1,000 balls with the offset die, and for this reason is not classified as an adopter. But we suspect that it will be revealed to be an adopter by our definition in a future survey round.[29]

### 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. However, 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, and if the cutters and printers are better informed than the owner about the effectiveness of the technology, they have an incentive to resist adoption of the new technology by misinforming the owner about the value of the technology.

We now develop a principal-agent cheap-talk model that captures this intuition and motivates our second experiment, which we present below in Section 7. The model is designed

[29] Our survey team's report continues,

> *He told us that his business is worth pkr 40 million. By giving him just pkr 4000 worth of die, we are trying to get a lot of information out of him which he doesn't like to give. He said that we are lucky because our offset die really works (give better results); that's why he got trapped. Else he wouldn't have responded to us at all.*

to be as simple as possible but still to capture what we believe are the main forces at play. Specifically, it shows that under certain parameter values there exists a scenario in which an imperfectly-informed owner, acting rationally, may choose not to adopt a beneficial technology due to misinformation from the cutter, who also acts rationally and is perfectly informed about the efficacy of the technology. We then describe an organizational innovation, a small expansion of the contract space, that may alleviate the misaligned-incentives problem and which closely maps to the incentive-payment experiment described below.

As mentioned in the introduction, our model combines insights from the literature on strategic communication that has grown out of Crawford and Sobel (1982), reviewed by Farrell and Rabin (1996) and Sobel (2013), and the literature on contracting within the firm (e.g. Holmstrom and Milgrom (1991) and Gibbons (1987)). It is most closely related to the small literature that combines the two streams, for instance Dessein (2002) and Krishna and Morgan (2008). We view the model primarily as an application of ideas from these literatures to our setting, which helps to organize our thinking about the owner-cutter interaction and to motivate our second experiment.

### 6.2.1 Set-up

We consider a one period game. There is a principal (she) and an agent (he). 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 $pq - w(q) - cq$. 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, which is not contractible. The agent expends effort at a cost of $e(a) = \frac{a^2}{2}$ and has utility $U() = w(q) - \frac{a^2}{2}$.

We 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. Adopting the new technology requires that the principal incur a fixed cost of $F$ to purchase necessary equipment and adapt the technology to the existing production process. The new technology potentially affects the agent's speed $s$ and the materials cost $c$. The old technology has known parameters $(s_0, c_0)$. There is uncertainty over the parameters of the new technology. More precisely, the principal knows that the new technology is one of three possible types:

1. Type 1 has parameters $(c_1, s_1)$, with $c_1 = c_0$ and $s_1 < s_0$. This technology is dominated by the existing technology because it does not lower material costs and is slower. We refer to this as the bad technology.

2. Type 2 has parameters $(c_2, s_2)$, with $c_2 < c_0$ and $s_2 < s_0$. This technology lowers material

costs but is slower than the existing technology.

3. Type 3 has parameters $(c_3, s_3)$, with $c_3 = c_0$ and $s_3 > s_0$. This technology dominates the existing technology because it is faster (even though it does not lower material costs).

The principal has a prior probability $\rho_i$ that the technology is of type $i$ with $\sum_1^3 \rho_i = 1$. We assume that the agent knows the type of technology with certainty.

The timing of the game is as follows. In Stage 1, the principal chooses a single wage contract.[30] In Stage 2, the agent can send one of three costless messages, $\{m_1, m_2, m_3\}$, regarding the type of the new technology. In Stage 3, the principal decides whether or not to adopt the new technology, taking into account the agent's message. In Stage 4 the profits and payments are realized and the technology is revealed to the principal. The key feature of the timing is that the wage contract must be chosen before the characteristics of the technology are revealed. Below we will consider cases which differ in the ability of the principal to condition the wage contract on revealed-ex-post information about the technology.

Given the structure of the game, it does not matter whether the technology is revealed to the agent before Stage 1 or before Stage 2. Thus the model can accommodate the scenarios either (a) that the principal's priors are set when the technology arrives and is revealed to the agent (e.g. during a visit from our survey team), or (b) that the principal's priors (and the wage contract) are set many months in advance of the technology arriving.

### 6.2.2 Benchmark 1: Fully informed principal

As a preliminary step, it is instructive to solve the model under the assumption that the principal is perfectly informed of the technology's parameters. In this case the principal will compare her profits under the new technology (with its optimal piece rate) with her profits under the existing technology (with its optimal piece rate), and choose to adopt the new technology if the profits under it are sufficiently high to cover the fixed cost of adoption $F$.

The agent's participation constraint (PC) is that the payoff to participating in the contract is at least as great as his outside option, which we denote by $\bar{u}$. The incentive compatibility constraint (ICC) is that he will choose non-contractible effort optimally given his utility function. The limited liability constraint (LLC), mentioned above, is that the fixed component of the wage cannot be negative. The optimal piece rate under any specific technology $i \in \{0, 1, 2, 3\}$ is

[30] We restrict attention to a single contract rather than a menu of contracts since there was no evidence such menus were on offer in Sialkot.

obtained by maximizing the principal's profit subject to these three constraints:

$$\begin{array}{llll} \max_{a,\beta} & ps_i a - (\alpha + \beta s_i a) - c_i s_i a & & \text{s.t.} \\ & \alpha + \beta s_i a - \frac{a^2}{2} & \geq \bar{u} & \text{(PC)} \\ & \arg\max_a \alpha + \beta s_i a - \frac{a^2}{2} & = a & \text{(ICC)} \\ & \alpha & \geq 0 & \text{(LLC)} \end{array}$$

As is well known in such principal-agent settings, in the absence of the limited-liability constraint the principal would make the agent the residual claimant: she would set $\beta = p - c_i$ and bring the agent down to his reservation utility through a negative value of $\alpha$. With the limited-liability constraint this is not possible. Since the agent's effort is independent of $\alpha$, the principal will choose to set $\alpha = 0$.

The optimal effort choice for the agent is to set $a = \beta s_i$. Given that the principal sets $\alpha = 0$, the agent's utility is pinned down in this case (and in all subsequent cases we will consider) by the piece rate and the speed of the technology:

$$U(\beta, s_i) = \frac{\beta^2 s_i^2}{2} \tag{1}$$

Feeding the agent's optimal effort into the principal's problem and solving for $\beta$, we obtain the optimal contract for a known technology $i$:

$$\alpha_i = 0,\ \beta_i = \frac{p - c_i}{2} \tag{2}$$

Since $c_1 = c_3 = c_0$, the optimal piece rate for technologies 1 and 3 is the same as under the existing technology. In contrast, the optimal piece rate for the material saving technology, technology 2, is higher since $c_2 < c_0$. In this case, the principal wants to incentivize more effort from the agent because profits per cut are higher.

The principal's profit from adopting technology $i$ as a function of the piece rate $\beta$ is given by:

$$\pi_i(\beta) \quad = \quad s_i^2 \beta\,(p - \beta - c_i) - F \cdot \mathbf{1}(i = 1, 2, 3) \tag{3}$$

Hence, the agent will adopt technologies of type 2 and 3 as long as both are more profitable (under their optimal piece rates) than the existing technology under its optimal piece rate, that is, as long as

$$\pi_2(\beta_2) \quad > \quad \pi_0(\beta_0) \tag{4}$$

$$\pi_3(\beta_3) \quad > \quad \pi_0(\beta_0) \tag{5}$$

#### 6.2.3 Benchmark 2: Imperfectly informed principal, no signaling from agent

As another preliminary step, it is useful to solve the model under the assumptions that the principal is imperfectly informed about the technology and the agent is unable to send a message about the technology. In this case, the principal must base her decision solely on her priors about the technology type, given by $\rho_i$ for $i = 1, 2, 3$.

Following the same logic as above, it can be shown that the principal chooses the wage contract:

$$\alpha = 0, \beta' = \sum_{i=1}^{3} \lambda_i \beta_i \tag{6}$$

where $\beta_i$ is defined as in (2) and $\lambda_i = \frac{\rho_i s_i^2}{\sum_1^3 \rho_i s_i^2}$. That is, the optimal piece rate in this case is a weighted average of the optimal piece rates in the full-information case, where the weights depend on the principal's priors and the speeds of the different technology types. Given this contract, the expected profit is:

$$\pi' = \left( \sum_{i=1}^{3} \rho_i s_i^2 \right) \left(\beta'\right)^2 - F \tag{7}$$

with $\beta'$ defined as in (6). In this case, the principal will not adopt if the expected profit from doing so is less than the (certain) profit from using the existing technology:

$$\pi' < \pi_0(\beta_0) \tag{8}$$

#### 6.2.4 Imperfectly informed principal, with signaling from agent

We now turn to the setting of primary interest in which the agent is imperfectly informed and can receive messages from the agent about the type of the new technology. We consider two cases, one in which the principal is unable to condition the wage payment on ex-post-revealed characteristics of the technology and one in which she can, subject to a fixed cost.

As noted above, one aim of the model is to show that there exists an equilibrium in which a perfectly informed agent misinforms an imperfectly informed principal about the value of the technology, and the principal is persuaded by the agent's signal not to adopt. This equilibrium does not exist for all possible parameter values. In order to focus attention on what we consider to be the interesting case in the model, we impose three parameter restrictions. Using the definitions of $\beta_i$ from (2), of $\pi(\cdot)$ from (3), and of $\pi'$ from (7) the restrictions can be stated as follows:

$$\pi_2(\beta_0) > \pi_0(\beta_0) \tag{9a}$$

$$\pi_3(\beta_2) > \pi_0(\beta_2) \tag{9b}$$

$$\pi_0(\beta_0) > \pi' \tag{9c}$$

The motivation for these conditions will be clearer below, but let us explain briefly here. Condition (9a) requires that technology type 2 be more profitable for the firm than the existing technology even under the optimal piece rate for the existing technology (which is not optimal for type 2). Note that this in turn implies (4), i.e. that a fully informed principal would adopt type 2, since $\beta_2$ is optimal for type 2 and hence $\pi_2(\beta_2) > \pi_2(\beta_0)$. Condition (9b) implies that technology 3 dominates the existing technology even at the optimal piece rate for technology 2 (which is not optimal for either technology 3 or the existing technology). Note that this in turn implies (5), i.e. that a fully informed principal would adopt type 3, since the derivative of $(\pi_3(\beta) - \pi_0(\beta))$ with respect to $\beta$ is weakly negative in the range $\beta \in [\beta_0, \beta_2]$. Condition (9c) is a restatement of (8); if it holds, a principal with no information beyond her priors will choose not to adopt.

#### 6.2.4.1 No conditional contracts

First we consider the case in which the principal is unable to condition the wage contract on characteristics of the technology that are revealed in Stage 4. In this case, there is an equilibrium in which the agent misinforms the principal about technology 2 and the principal is persuaded not to adopt.

**Proposition 1.** *In the game described above (without conditional contracts), the following set of strategies is part of a perfect Bayesian equilibrium.*

1. *Agent's strategy:*
   (a) *If the technology is of type 1 or type 2, signal $m_1$*
   (b) *If the technology is of type 3, signal $m_3$.*
2. *Principal's strategy:*
   (a) *Offer wage contract $\left(\alpha^* = 0, \beta^* = \frac{p-c_0}{2}\right)$*
   (b) *If agent signals $m_2$ or $m_3$, adopt.*
   (c) *If agent signals $m_1$, do not adopt.*

The proof is in appendix A.2. Intuitively, in this case the principal must commit to a piece rate ex ante. Given that she has done so, the agent wants to prevent the adoption of technology 2, since it is slower, so if the technology is type 2 the agent signals that it is type 1, the bad technology. The interesting question is why the principal pays attention to the agent's signal, given that she knows that the agent has the incentive to misinform her in this way. The general answer is the agent's signal may be "influential" in the sense discussed by Sobel (2013) when two conditions are satisfied: (1) the agent's and principal's interests are sufficiently aligned that for some technology types the agent and principal favor the same adoption decision, and (2) the agent's preferences over adoption vary across technology types. These conditions are satisfied here: the players' interests are aligned if the technology is of type 1 or 3, and the agent's preferences for adoption differ across these types. The agent's advice is valuable enough in these states of the world that it is worthwhile for the principal to follow the agent's advice and allow herself to be misled in the type-2 state rather than ignore the agent's advice altogether.

There is also a "babbling" equilibrium in which the principal ignores what the agent says and the agent can say anything. In this equilibrium, the principal bases her decision solely on her priors, as in Section 6.2.3. Given Condition (9c), she does not adopt. As in other cheap-talk models, there are many other possible equilibria. The literature has developed a number of equilibrium refinements to eliminate implausible equilibria, which are not our focus here; see Sobel (2013) for further discussion.

An important question that arises here is whether there exists an equilibrium in which the agent reveals the technology type truthfully. It turns out that under conditions (9a)-(9c) there does not.

**Proposition 2.** *In the game described above, there is no perfect Bayesian equilibrium under which the agent always truthfully reveals the technology type.*

The formal proof is in Appendix A.3. Intuitively, if the agent were to reveal the technology type truthfully, then under our conditions the principal would want to adopt type 2 and not type 1. But given this strategy of the principal, and the fact that the wage contract is fixed ex ante, the agent would be better off misreporting type 2 to be type 1, discouraging adoption of the slower type 2 technology.

In sum, under piece-rate contracts that must be specified ex ante (and not conditioned on ex-post-revealed features of the technology), we have two main results. First, the sort of behavior we have observed in Sialkot, where cutters misinform owners about the value of the offset die and the owners are persuaded by them, is an equilibrium of our strategic-communication game. Second, some information that the cutters have about technologies is necessarily lost because of conflicting incentives within firms.

#### 6.2.4.2 Conditional contracts

Now suppose that the principal can pay a fixed cost, $G$, and have access to a larger set of wage contracts. In particular, suppose that after paying the fixed cost $G$ she can credibly commit to paying a different piece rate if the technology is revealed to be of type 2. (This is the type for which the ability to condition the contract is useful, since $c_3 = c_1 = c_0$ and hence $\beta_3 = \beta_1 = \beta_0$:

the optimal contracts under the other three technologies are identical.) That is, the principal can offer contracts of the form:

$$w(q) = \alpha + \beta q + \gamma q \qquad \text{if } c = c_2$$

$$w(q) = \alpha + \beta q \qquad \text{if } c \neq c_2$$

If $G$ is sufficiently small, then there will exist an equilibrium in which the agent reveals truthfully.

**Proposition 3.** *In the game described above (with conditional contracts), if*

$$G < \rho_2 \left[\pi_2(\beta_2) - \pi_0(\beta_0)\right] \tag{10}$$

*then the following set of strategies is part of a perfect Bayesian equilibrium for the conditional wage contract game.*

1. *Agent's strategy:*
   - (a) *If the principal pays $G$, signal truthfully.*
   - (b) *If the principal does not pay $G$:*
     - i. *If the technology is of type 1 or 2, signal $m_1$.*
     - ii. *If the technology is of type 3, signal $m_3$.*
2. *Principal's strategy:*
   - (a) *Pay $G$ and offer wage contract* $\left(\alpha^{**} = 0, \beta^{**} = \frac{p-c_0}{2}, \gamma^{**} = \frac{c_0-c_2}{2}\right)$
   - (b) *If the agent signals $m_2$ or $m_3$, adopt.*
   - (c) *If the agent signals $m_1$, do not adopt.*

The proof is in Appendix A.4. Intuitively, the ability to condition the contract allows the principal to commit ex ante to a higher piece rate if the technology is of type 2. Note that using the notation of (2), $\beta^{**} = \beta_0$ and $\beta^{**} + \gamma^{**} = \beta_2$, the optimal piece rate for type 2 in the full-information case. If the principal pays the fixed cost, $G$, and offers the conditional contract, then the higher piece rate for type 2 is enough to induce the agent to prefer adoption if the technology is of type 2. Doing so will be in the interest of the principal if (10) is satisfied, which is to say that the expected additional profit from adopting type 2 (with the optimal piece rate for type 2) is greater than the fixed cost of using the new contract.

### 6.2.5 Discussion

We have shown that when the principal has to commit to a standard piece-rate contract ex ante, there may exist an equilibrium in which the agent misinforms the owner about a technology of type 2, and the principal is influenced by the agent not to adopt it. This is consistent with anecdotal and qualitative survey evidence from Sialkot about the reasons that some owners have not adopted the new offset dies.

We have also shown that a relatively simple modification to the labor contract, conditioning the piece rate on the ex-post-revealed characteristics of the technology, can solve the misinformation problem in the sense that, for a sufficiently low fixed cost, there is an equilibrium with truthful revelation and adoption of the type-2 technology. This again is consistent with some anecdotal evidence from the sector.

A natural question that arises in this environment is why, if the simple contract modification can solve the misinformation problem, the principal would not simply choose to offer the conditional contract. Our model suggests two possible reasons, which we believe apply in the real-world context we are focusing on. One reason is simply that the principal is not aware of the existence of the conditional contract. In this sense, the conditional contract may be an organizational innovation that was previously unknown, at least to some firms, in the same way that our offset die and cutting design was previously unknown.

Another possible reason is that the principal is aware of the availability of the conditional contract, but the cost of implementing it is too high to be worth offering it. The fixed cost of offering the new contract can be interpreted in a number of different ways. It may be that social norms have arisen around standard fixed rate contracts, such that firms incur a cost, in terms of reduced worker morale or active malfeasance, if they deviate from the contract perceived to be normal or fair.

The fixed cost can also be interpreted as a cost of accessing a commitment device to make credible the principal's pledge to raise the piece rate if the technology is revealed to be of type 2. That is, although the principal may promise to alter the piece rate in this way, such a promise is unlikely to hold up in a court, particularly in a setting with relatively weak legal institutions such as Sialkot, and committing credibly to modifying the piece rate may be quite costly. In our simple model, such commitment would not be needed since it is optimal for the principal to pay a higher piece rate to induce additional effort even after the material-saving technology is revealed. However, such a commitment device may be needed in more complicated models with additional dimensions of uncertainty.

Finally, the fixed cost can be interpreted in light of the well-known ratchet effect that can occur in more complex models of both hidden action and hidden information (e.g. Gibbons (1987)). If most technologies are labor saving, such as the type-3 technology, the worker may not bring these to the attention of the owner if he expects the principal to cut his wage in response. In these settings, as in the Lincoln Electric case discussed in Carmichael and MacLeod (2000), it can be optimal for the principal to commit to not changing the piece rate in order to encourage labor-saving innovation. If most innovations in Sialkot are labor saving, such concerns may explain why piece rates are sticky and why it may be costly for firms to start offering conditional contracts that open the door to the ratchet effect. Anecdotally, several firms and die-makers reported to us that the last major cutting innovation was a shift from a one-pentagon die to the two-pentagon non-offset die (e.g. two pentagons sharing a full edge, see Figure 7), which was a labor-saving innovation. Thus, it is reasonable to think that firms in Sialkot expect new cutting technologies to be labor rather than material saving and have put in place the appropriate incentive structure to encourage such innovations.

In the model, if conditional contracts are available but the fixed cost $G$ is high, that is if (10) is not satisfied, then there again exists the equilibrium of Proposition 1 and the type-2 technology may not be adopted. In addition, it is worth emphasizing that the condition on the magnitude of the fixed costs, (10), is a statement about the costs of contract modification relative to the expected additional profit from adopting the type-2 technology, where the expected additional profit depends on the principal's prior that the technology is of type 2, $\rho_2$. If the principal is initially very skeptical, she may not be willing to offer the conditional contract, even at a modest fixed cost.

In our model, the two reasons for not modifying wage contracts — ignorance of the availability of the such contracts and high fixed costs of adopting them — have similar implications for the players' behavior. As mentioned above, the misinformation equilibrium exists in both circumstances. What is clear, however, is that if an external third party implemented the conditional contract, we would expect the agent to reveal truthfully and the principal to adopt a technology of type 2. This is the intervention that our second experiment is designed to mimic.

# 7 Experiment 2: The Incentive-Payment Experiment

## 7.1 Experimental design

To test the hypothesis that a conflict of interest within firms tends to hinder adoption, in September-November 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 only the 35 tech-drop firms (including both initial responders and initial non-responders) to which we gave the blueprint and die. 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 August 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 also offered to do a new demonstration with their cutters. Finally, we 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 the same information about the two-pentagon variant. In addition, we explained to the owner that cutters and printers on piece-rates had an incentive to misinform the owner about the value of the technology. We also 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 demonstrates competence in using the new die and the printer demonstrates competence in printing pairs of offset pentagon pieces cut by the new die.

This incentive-payment treatment is designed to mimic the conditional contracts in the theoretical model discussed in Section 6 above. While in the theory the conditional contract involves a change in the piece rate conditional on adoption of a new technology (recall that at cost $G$ the firm can pay an additional piece rate of $\gamma^{**}$ if the technology is revealed to be of type 2), we were constrained in the experimental design by the limited willingness of firms to participate. Although most firms to which we offered the incentive-payment treatment accepted, our interactions with them suggested that they were extremely unlikely to furnish the sort of detailed production information that would allow us to modify piece rates. We therefore chose to offer a single lump-sum payment, which required less time and information from firms to implement but would still induce the cutter to reveal the efficacy of the new technology. Even so, five of the 15 firms that were offered the incentive-payment treatment refused to participate. We believe that it was simply not possible to manipulate the piece rate itself, and we opted for a one-time bonus payment as a reasonable second-best option.

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.[31] 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

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

die in three minutes.[32] 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.[33]

Table 11 evaluates baseline balance by comparing firm characteristics across Group A and Group B firms at the time of our visit to explain the intervention (September 2013). No differences in means are statistically significant. It appears that randomization was successful.[34]

### 7.2 Results

Ten of the 15 Group A firms agreed to participate in the experiment.[35] Table 12 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). The minimum time reported using the offset die was 2 minutes and 28 seconds, or 9.6 percent longer than the traditional die. Partly for this reason, and the fact that cutters do not need to change sheets as frequently with the new die, 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 cutting time. 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.

In order to investigate subsequent adoption, we carried out a survey round in January-March 2014, 2-5 months after the completion of the incentive-payment intervention. 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 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, 5 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.

[32] The 3-minute targets were chosen after conducting speed tests at two of the 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 using the original die.

[33] 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.

[34] 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.

[35] In two of these 10 firms, it was not possible to complete the printer performance test.

Table 13 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 August 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 dependent variable in Columns 2-4 and 6-8 is a 0/1 indicator for whether a firm has adopted, i.e. is currently using the offset die and has produced more than 1,000 balls using it. The OLS estimates in Columns 2 and 6 are positive and significant, but one might be worried about selection into treatment. The reduced-form (intent-to-treat) results do not suffer from such selection issues and indicate a positive and significant (at the 5 percent level) causal relationship between assignment to Group A (the incentive-payment treatment) and adoption. Adoption rates increased by 0.32 among the treatment group or by 0.38 if we restrict attention to only the firms who had not already adopted at the start of the experiment. The IV estimates (the effect of treatment on the treated) are substantially higher (0.48 or 0.63 if we restrict attention only to initial non-adopters). However, since the one third of firms who refused the intervention may have chosen to do so because of particularly large costs of adoption (or small benefits), these IV estimates should be treated with caution.

To check robustness, Table 14 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 September 1, 2013. Of the eight firms that accepted the intervention and had not adopted by August 2013, three subsequently purchased their first offset die. (One of these firms had not produced with it yet at the time of our most recent survey.)[36] Table 14 shows that the positive causal effect of the incentive-payment treatment on adoption is robust to using this alternative measure.

It is important to acknowledge that the sample sizes in the incentive-payment experiment are small. An alternative to large-$N$ statistical inference are permutation tests whose properties are independent of sample size (see Bloom et al. (2013) for the use of this type of inference in a similar context). We determine the proportion of all possible treatment assignments that produce coefficients as or more extreme than the ones we find. This procedure produces an exact p-value and so does not require any asymptotic approximations. Given the selection discussion above, we focus on the more conservative ITT estimates in columns 3 and 7 of Tables 13 and 14. Within each of the four strata, we assigned treatment status with 50 percent probability. The stratum with the smaller firms contained 6 firms, the stratum with the larger firms contained 12 firms, the stratum with the initial non-responders contained 8 firms and the stratum of

[36] In addition, one large Group-A firm that was already classified as an adopter because it was using the offset cutting pattern for table cutting (see footnote 11), purchased its first die (beyond the four-panel offset die we originally gave) following the beginning of our intervention.

already-adopters had 5 firms. This means there are $25,872,000 = \binom{6}{3}\binom{12}{6}\binom{8}{4}\left(\binom{5}{2}+\binom{5}{3}\right)$ possible treatment assignments.[37]

Figure 15 plots the distribution of coefficients obtained from regressing die use on assignment to group A for the millions of possible treatment assignments. The left panel reports the distribution of outcomes under the specifications with all strata and the right panel reports outcomes from the initial non-adopters sample only. The vertical line in both figures denotes the observed ITT effects reported in columns 3 and 7 of Table 13. Note that there are only a handful of possible coefficients despite the several million possible permutations. This is because of the small number of adopting firms and because no control firm has adopted the die. Yet in both cases, the observed ITT coefficients are the largest effects that could have been observed under any treatment assignment. In other words, there is no possible outcome that is more extreme than the one we observe in each specification. We can use the distribution to construct p-values for the hypothesis test that the coefficients we find are different from zero. For our main measure of adoption, current use, the p-value is 3.04 percent in both the all firm and initial non-adopter samples. Figure 16 presents a similar analysis for our alternative indicator of adoption, die purchases, with corresponding p-values of 4.28 percent in the all-firm sample and 21.42 percent in the initial non-adopters sample.

The results indicate a robust effect of the incentive payment treatment on adoption. Using current use ($> 1,000$ balls), it is striking that over half of the treated firms that had not previously adopted responded to the treatment. 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 empirical findings. First, despite the apparent advantages of the technology we invented, a surprisingly small number of firms have adopted it, 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

[37] If we exclude the already-adopter stratum, there are $1,293,600 = \binom{6}{3}\binom{12}{6}\binom{8}{4}$ possible permutations.

the hypothesis that a misalignment of incentives within the firm — in particular, employees paid piece rate have an incentive to resist adoption of a material-saving technology that slows them down — is an important barrier to adoption. Although for most firms we do not observe directly the communication between employees and owners, it appears that at least one way that employees have resisted the adoption of our new technology is by misinforming owners about the value of the technology. It further appears that the incentive-payment intervention had a significant effect because it induced workers to report truthfully to owners.

One broader conclusion that emerges from this study is that in order for technology adoption to be successful, employees have to have a credible expectation that they will share in the gains from adoption. We have argued that in this case the net benefits from adoption are clearly positive, but also that in most firms, if there is not a change in labor contracts, cutters' incomes will fall. Not expecting owners to change labor contracts, employees in many firms appear to have successfully blocked adoption. Although our study is focused on a particular industry in a particular cultural context, we believe that the conclusion that workers must expect to share in gains from adoption for adoption to be successful is potentially quite general.

The natural question that arises is why firm owners do not simply change the payment scheme they offer workers. We have considered two possible explanations. One is simply that owners were simply not aware of the availability of alternative payment schemes, or did not understand that an alternative scheme would be desirable. 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 such norms. Other explanations for the existence of transaction costs are also possible. It may be that firms want to commit not to changing piece rates, so as to convince employees that there will not be ratchet effects from sharing labor-saving productivity improvements. It may also be that it is difficult for owners to commit credibly to offering contracts conditional on successful adoption. Whatever the source of the transaction costs, owners will weigh them against the expected benefits of adopting new technologies. If owners have low priors that new technologies that arrive are beneficial, they may rationally be unwilling to pay even quite small transaction costs. In any case, the important point for the current paper 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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# A Theory appendix

## A.1 Preliminary claims

We make several small claims that will be useful for proving the various propositions.

**Claim 1.** *Suppose there exists a Perfect Bayesian Equilibrium (PBE) where*

$$\sigma_A(m_i|t_i,\beta) = 1;\ i = 1,2,3,\ \ \forall\ \beta$$

*where $\sigma_A$ is the agent's equilibrium signaling strategy and $t_i = (c_i, s_i)$ is technology $i$. Then*

$$\sigma_P(adoption \mid m_1, \beta) = 0$$

*Proof.* $\sigma_A(m_i|t_i,\beta) = 1;\ i = 1,2,3$ implies that the principal has the beliefs $\mu(t_i \mid m_i, \beta) = 1;\ i = 1,2,3$ in equilibrium. Hence following the signal $m_1$, the principal knows that the technology realized is $t_1$. Therefore it suffices to show that

$$\pi_1(\beta) < \pi_0(\beta)$$

This is true since $s_1 < s_0$ and $c_1 = c_0$. □

**Claim 2.** *Suppose that there exists a PBE where*

$$\sigma_A(m_i|t_i,\beta) = 1;\ i = 1,2,3\ \ \forall\ \beta$$

*Let $\beta^*$ be the optimal contract offered by the principal in that PBE. Then*

$$\beta^* \in [\beta_0, \beta_2]$$

*Proof.* Let $\Omega_2$ be the set of feasible $\beta$ such that

$$\beta \in \Omega_2 \quad \Rightarrow \quad \pi_2(\beta) = \pi_0(\beta)$$

Similarly let $\Omega_3$ be defined as the set of feasible contracts such that

$$\beta \in \Omega_3 \quad \Rightarrow \quad \pi_3(\beta) = \pi_0(\beta)$$

We now show that $(\Omega_2 \cup \Omega_3) \not\subset [\beta_0, \beta_2]$. From condition (9a) we get that $\pi_2(\beta_0) > \pi_0(\beta_0)$ and $\pi_2$ is increasing in the range $[\beta_0, \beta_2]$ while $\pi_0$ is decreasing. Hence $\Omega_2 \not\subset [\beta_0, \beta_2]$. Similarly condition (9b) says that $\pi_3(\beta_2) > \pi_0(\beta_2)$ and $\pi_3(\beta) - \pi_0$ is weakly decreasing in the range $[\beta_0, \beta_2]$. Therefore $\Omega_3 \not\subset [\beta_0, \beta_2]$.

Now suppose that it is possible to have the optimal contract in the PBE $\beta^*$ lie outside $[\beta_0, \beta_2]$. Suppose $\beta^* \notin (\Omega_2 \cup \Omega_3)$. Then by construction and by Claim (1), the principal plays a pure (adoption) strategy at $\beta^*$. Now notice the fact that $\pi_i(.),\ i = 0, 1, 2, 3$ are all decreasing for $\beta > \beta_2$ and all increasing for $\beta < \beta_0$. Let $\pi^*(\beta^*)$ be the expected profit to the principal in an equilibrium with contract $\beta^*$. Then $\pi^*(\beta^*)$ is some convex combination of $\pi_i(\beta^*),\ i = 0, 1, 2, 3$. Given that the principal plays a pure strategy at $\beta^*$, she would not change her adoption strategy in the small neighborhood around $\beta^*$. But that implies that $\pi^*$ is either increasing in $\beta^*$ (if $\beta^* < \beta_0$) or decreasing in $\beta^*$ (if $\beta^* > \beta_0$) in its small neighborhood. Hence $\beta^*$ can not be optimal.

Now let $\beta^* \in \Omega_2$. Hence by construction the principal is indifferent between adoption of technology 2 and non-adoption. In that case if the principal chooses to mix across adoption and non-adoption, then $\sigma_A(m_i|t_i, \beta) = 1$ for all $i$ would not be the optimal strategy for the agent at $\beta^*$; specifically the agent upon observing $t_2$ would strictly prefer to report $m_1$ as that would result in non-adoption (by Claim 1) which gives him higher payoff than a randomization over adoption and non-adoption. If the principal still has a pure strategy at that $\beta^*$ then she can do better by changing the contract to some other $\beta$ in the neighborhood of $\beta^*$, by the previous argument.

Now let $\beta^* \in \Omega_3$. Therefore, the principal is indifferent between adoption of technology 3 and non-adoption. Suppose the principal randomizes between them at $\beta^*$ (pure strategies again will not be optimal by the previous argument). We first consider the case: $\pi_2(\beta^*) > \pi_0(\beta^*)$. In that case the agent upon observing $t_3$ would strictly prefer to report $m_2$ as that would result in adoption which the agent strictly prefers to randomization over adoption and non-adoption. Now let's consider the other case: $\pi_2(\beta^*) < \pi_0(\beta^*)$.[38] Let $\beta^* > \beta_2$. Then a deviation by the principal to offer $(\beta^* - \epsilon)$ would result in better expected profit for some positive $\epsilon$ because (1) $\pi_i$ for all $i$ are decreasing for $\beta > \beta_2$, (2) the principal strictly prefers adoption of technology 3 and non-adoption of technology 2 for all $\beta \in [\beta^* - \epsilon, \beta^*]$, (3) the agent's strategies are the same in $[\beta^* - \epsilon, \beta^*]$ and therefore (4) the principal's expected payoff $\pi^*$ is continuous in $[\beta^* - \epsilon, \beta^*]$ and as a consequence (5) the principal's profit at $\beta^* - \epsilon$ is higher than at $\beta^*$.
Similar arguments hold if $\beta^* < \beta_0$. Hence $\beta^* \notin [\beta_0, \beta_2]$ can not be optimal.

□

**Claim 3.** *Suppose there exists a PBE where*

$$\sigma_A(m_i|t_i, \beta) = 1;\ i = 1, 2, 3\ \forall\ \beta$$

[38] The case of $\pi_2(\beta^*) = \pi_0(\beta^*)$ has been covered in the previous discussion of $\beta^* \in \Omega_2$.

*Then*

$$\sigma_P(adoption \mid m_2, \beta^*) = 1$$

*where $\beta^*$ is the equilibrium contract in the PBE.*

*Proof.* As before $\sigma_A(m_i|t_i, \beta) = 1;\ i = 1, 2, 3$ implies that the principal has the beliefs $\mu(t_i \mid m_i, \beta) = 1;\ i = 1, 2, 3$ in equilibrium. We note that these beliefs imply that in equilibrium the principal knows that the technology realized is $t_2$ when the agent signals $m_2$. Hence the result would be true if we have for any equilibrium contract $\beta^*$,

$$\pi_2(\beta^*) > \pi_0(\beta^*)$$

which follows from the chain of inequalities:

$$\pi_2(\beta^*) \geq \pi_2(\beta_0) > \pi_0(\beta_0) \geq \pi_0(\beta^*)$$

The first inequality is true since $\pi_2(.)$ is increasing in $\beta \in [\beta_0, \beta_2]$, and we only consider $\beta^* \in [\beta_0, \beta_2]$ because of Claim (2). The second inequality follows from condition (9a). The last inequality holds as $\beta_0$ maximizes $\pi_0$. □

**Claim 4.** *Suppose there exists a PBE where*

$$\sigma_A(m_1|t_1, \beta) = \sigma_A(m_1|t_2, \beta) = 1 \ \ and \ \ \sigma_A(m_3|t_3, \beta) = 1 \ \ \forall \ \ \beta$$

*Let $\beta^*$ be the optimal contract offered by the principal in that PBE. Then*

$$\beta^* \in [\beta_0, \beta_2]$$

*Proof.* If the principal's adoption strategy is pure at some $\beta^* \notin [\beta_0, \beta_2]$ then $\beta^*$ cannot be optimal by the same logic as in Claim (2). If the principal is indifferent between adoption and non-adoption following some signal then also her strategies are essentially not changing in some neighborhood of $\beta^*$ (i.e. her expected payoff is continuous in some neighborhood of $\beta^*$) as explained before. Hence $\beta^* \notin [\beta_0, \beta_2]$ cannot be optimal. □

## A.2 Proof of Proposition 1

It suffices to show that there is no profitable deviation for either principal or agent.

**No Incentive For Agent to Deviate:** First we show there is no incentive for the agent to deviate from his signaling strategy holding fixed the principal's strategy. Conditional on the piece rate being held fixed, the agent strictly prefers faster technologies since his utility is increasing in $s$:

$$U(\beta, s) = \frac{\beta^2 s^2}{2}$$

Formally there is no different strategy $\sigma'_A$ which gives the agent higher payoff given the principal's strategy

$$\sigma_P(\text{adoption} \mid m_1) = 0$$
$$\sigma_P(\text{adoption} \mid m_2) = 1$$
$$\sigma_P(\text{adoption} \mid m_3) = 1$$

If the technology is of type 2, the agent signals $m_1$. The agent does not have an incentive to deviate and signal $m_2$ or $m_3$ as this would induce adoption and

$$\frac{\beta^2 s_2^2}{2} < \frac{\beta^2 s_0^2}{2}$$

If the technology is of type 3, the agent signals $m_3$ and the principal adopts. He has no incentive to deviate and signal $m_1$, which induces the principal not to adopt, because

$$\frac{\beta^2 s_0^2}{2} < \frac{\beta^2 s_3^2}{2}$$

He also has no (strict) incentive to deviate and signal $m_2$, since this also induces adoption and leads to the same payoff as signaling $m_3$. If the technology is of type 1, the agent signals $m_1$ and the principal does not adopt. The agent has no incentive to deviate and signal $m_2$ or $m_3$, which will induce the principal to adopt, since

$$\frac{\beta^2 s_1^2}{2} < \frac{\beta^2 s_0^2}{2}$$

**No Incentive For Principal to Deviate:** Now we show that there is no incentive for the principal to deviate from her adoption strategy, holding fixed the agent's strategy. First we note that the beliefs of the principal given the three signals are given by: $\mu(t_1|m_1) = \rho_1/(\rho_1+\rho_2), \mu(t_2|m_1) = \rho_2/(\rho_1+\rho_2), \mu(t_2|m_2) = 1, \mu(t_3|m_3) = 1$, where $t_i = (c_i, s_i)$ is technology $i$, and the beliefs, except $\mu(t_2|m_2)$, are given by Bayes' Rule and the strategies of the agent. Since $m_2$ is never signaled on the equilibrium path, $\mu(t_2|m_2)$ is off-path belief and we specify it to be 1.

We show that the principal's strategy is optimal in two steps. First we find the optimal strategies for the principal in Stage 3 given the three possible signals she can receive under any contract $\beta^*$ signed in Stage 1. Then, anticipating her behavior in Stage 3, we find the optimal contract chosen in Stage 1.

**Optimal Adoption Strategies in Stage 3:**

If the signal is $m_3$ the principal knows that the technology is $t_3$ (since $\mu(t_3|m_3) = 1$). Hence the payoff from adoption and non-adoption are given by,

$$\pi(\text{adoption} \mid m_3, \beta^*) = \pi_3(\beta^*)$$
$$\pi(\text{non-adoption} \mid m_3, \beta^*) = \pi_0(\beta^*)$$

where $\beta^*$ is the equilibrium contract being offered. Hence the principal would adopt following signal $m_3$ if and only if

$$\pi_3(\beta^*) > \pi_0(\beta^*)$$

which is true because of (1) Claim (4), (2) condition (9b) and (3) the fact that $\pi_3(\beta) - \pi_0(\beta)$ is weakly decreasing in the range $[\beta_0, \beta_2]$.

If the signal is $m_1$ then the expected profit to the principal from adoption and non-adoption are given by,

$$\pi(\text{non-adoption} \mid m_1, \beta^*) = \pi_0(\beta^*)$$
$$\pi(\text{adoption} \mid m_1, \beta^*) = \frac{\rho_1}{\rho_1 + \rho_2}\pi_1(\beta^*) + \frac{\rho_2}{\rho_1 + \rho_2}\pi_2(\beta^*)$$

We know that $\pi_1(\beta^*) < \pi_0(\beta^*)$ (since $s_1 < s_0$ and $c_1 = c_0$). But condition (9a) implies $\pi_2(\beta^*) > \pi_0(\beta^*)$ for all $\beta^* \in [\beta_0, \beta_2]$. Hence, it is not a priori clear if the principal would like to adopt following signal $m_1$. Let $S_{1N}$ be the subset of $\beta^*$ for which the principal chooses not to adopt following signal $m_1$. Let $S_{1A}$ be the complimentary set. So $\beta^* \in S_{1A}$ implies that the principal would adopt the technology if the agent signals $m_1$. We note that $\beta_0 \in S_{1N}$, i.e. that the under the piece rate $\beta_0$ the principal will not want to adopt if the agent reports $m_1$. Specifically $\beta_0 \in S_{1N}$ must be true if

$$(\rho_1 + \rho_2)\pi_0(\beta_0) > \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0)$$

$$\iff \quad (\rho_1 + \rho_2)\pi_0(\beta_0) + \rho_3\pi_3(\beta_0) > \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) + \rho_3\pi_3(\beta_0) \tag{A1}$$

Condition (9c) implies that

$$(\rho_1 + \rho_2 + \rho_3)\pi_0(\beta_0) > \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) + \rho_3\pi_3(\beta_0)$$

since $(\rho_1 + \rho_2 + \rho_3) = 1$ and $\pi'$ is the maximum profit when the principal always adopts under no additional information. Hence

$$\pi' > \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) + \rho_3\pi_3(\beta_0)$$

$$\Rightarrow \quad (\rho_1 + \rho_2 + \rho_3)\pi_0(\beta_0) > \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) + \rho_3\pi_3(\beta_0)$$

$$\Rightarrow \quad (\rho_1 + \rho_2)\pi_0(\beta_0) + \rho_3\pi_3(\beta_0) > \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) + \rho_3\pi_3(\beta_0)$$

which follows from the fact that $\pi_3(\beta_0) > \pi_0(\beta_0)$ as implied by condition (9b). Hence the inequality (A1) is true.

Finally, if the signal is $m_2$ then the principal believes that the technology is $t_2$ given her off-path belief. Hence she would adopt the technology if

$$\pi_2(\beta^*) > \pi_0(\beta^*)$$

which is true because of condition (9a) and the fact that $\pi_2$ is increasing and $\pi_0$ is decreasing in the range $[\beta_0, \beta_2]$.

**Optimal Contracts in Stage 1:**

Finally we confirm that $\beta^* = \beta_0$ is the optimal contract for the principal to offer at Stage 1 given her adoption strategies and the agent's signaling strategy. Let $\pi^*(\beta^*)$ represent the expected payoff to the principal in the equilibrium where $\beta^*$ is the equilibrium contract. We partition the set of possible $\beta^*$, i.e. $[\beta_0, \beta_2]$ into 2 subsets: $S_{1N}$ and $S_{1A}$. We first show that:

$$\pi^*(\beta_0) = \max_{\beta^* \in S_{1N}} \pi^*(\beta^*)$$

This holds because $\beta^* \in S_{1N}$ implies

$$\pi^*(\beta^*) = (\rho_1 + \rho_2)\pi_0(\beta^*) + \rho_3\pi_3(\beta^*) \tag{A2}$$

Now writing the profit functions out in full, it is easy to show that $\beta^* = \frac{p-c_0}{2} = \beta_0$ maximizes $\pi^*$. Hence $\beta^* = \beta_0$ also maximizes $\pi^*$ when $\beta^* \in S_{1N}$.

Now $\beta^* \in S_{1A}$ implies

$$\pi^*(\beta^*) = \rho_1\pi_1(\beta^*) + \rho_2\pi_2(\beta^*) + \rho_3\pi_3(\beta^*) \tag{A3}$$

Hence

$$\sup_{\beta^* \in S_{1A}} \pi^*(\beta^*) \leq \pi' < \pi_0(\beta_0)$$

where the last inequality is by condition (9c) and the first one is by definition of $\pi'$.

Hence the principal prefers $\beta_0$ to all other possible contracts and hence $\beta_0$ is the optimal contract for the agent to offer. □

## A.3 Proof of Proposition 2

We have to show that there does not exist a PBE with

$$\sigma_A(m_i|t_i) = 1;\ i = 1,2,3$$

where $\sigma_A$ is agent's signaling strategy and $t_i = (c_i, s_i)$ is technology $i$.
We prove this proposition by contradiction. Assume that there is a PBE in which the agent signals truthfully.

In light of Claims (1) and (3) the principal will adopt if the agent reports $m_2$ and won't if the agent reports $m_1$. But we can find a profitable deviation for the agent when $t_2$ is realized. Formally there is a different strategy $\sigma'_A$ which gives the agent higher payoff where,

$$\sigma'_A(.|t_1) = \sigma_A(.|t_1),\ \ \sigma'_A(.|t_3) = \sigma_A(.|t_3),\ \text{and}\ \ \sigma'_A(m_1|t_2) = 1, \sigma'_A(m_2|t_2) = 0$$

Under the new strategy the expected payoff to the agent when $t_2$ is observed is:

$$\begin{aligned} U(\sigma'_A, \sigma_P|t_2) &= \frac{(\beta^* s_0)^2}{2} \\ &> \frac{(\beta^* s_2)^2}{2} \\ &= U(\sigma_A, \sigma_P|t_2) \end{aligned}$$

□

## A.4 Proof of Proposition 3

It once more suffices to show that there is no profitable deviation for either principal or agent.

Under this wage schedule, an agent observing a type 2 technology will not want to deviate (and signal something other than $m_2$) if the following condition holds:

$$\frac{((\beta^{**} + \gamma^{**})s_2)^2}{2} > \frac{(\beta^{**} s_0)^2}{2}. \tag{A4}$$

where the left-hand side is the Agent's utility if type 2 is adopted, and the right-hand side his utility under the existing technology (refer to 1). Noting that $\beta^{**} = \beta_0$ and $\beta^{**} + \gamma^{**} = \beta_2$, Condition (9a) implies (A4). The Agent also does not wish to deviate if he observes the other two types for identical reasons as in the proof of Proposition 1.

The principal's next-best strategy is not to pay $G$ and to follow the same strategy as in Proposition 1. The Principal will not deviate to this strategy if the following holds:

$$\rho_1 \pi_0(\beta_0) + \rho_2 \pi_2(\beta_2) + \rho_3 \pi_3(\beta_3) - G \quad > \quad (\rho_1 + \rho_2)\, \pi_0(\beta^*) + \rho_3 \pi_3(\beta^*)$$

where the left-hand side is the payoff to the strategy of Proposition 3 and the right-hand side is the payoff to the strategy of Proposition 1. Condition (10) ensures this holds, since $\beta^* = \beta_3 = \beta_0$. □

**Table 1: Pentagons per Sheet**

| | traditional die | | offset die | |
|---|---|---|---|---|
| | owner report (1) | direct obs. (2) | owner report (3) | direct obs. (4) |
| size 43.5 | 257.4 | 257.7 | 273.5 | 277.5 |
| | (10.4) | (6.7) | (4.4) | (5.3) |
| size 43.75 | 256.3 | 254.4 | 269.0 | 272.0 |
| | (6.2) | (9.4) | (1.4) | (0.0) |
| size 44 | 253.8 | 248.4 | 280.0 | 272.5 |
| | (8.4) | (18.7) | | (0.7) |
| size 44.25 | 246.1 | 262.0 | 272.0 | |
| | (8.3) | | | |
| rescaled (to size 44) | 253.6 | 248.3 | 280.0 | 272.9 |
| | (8.5) | (11.0) | (3.0) | (3.9) |
| N (after rescaling) | 274 | 39 | 8 | 10 |

Notes: Pentagons per sheet rescaled using means for each size in each column. The N in the final row corresponds to the pooled number of observations for all die sizes. Standard deviations reported in parentheses.

**Table 2: Production Costs**

| Input | Share of Production Costs (%) | Input Cost (in Rs) |
|---|---|---|
| rexine | 19.79 | 39.68 |
| | (5.37) | (13.87) |
| cotton/poly cloth | 12.32 | 23.27 |
| | (4.56) | (8.27) |
| latex | 13.94 | 38.71 |
| | (10.73) | (90.71) |
| bladder | 21.07 | 42.02 |
| | (4.87) | (14.09) |
| labor for cutting | 0.76 | 1.47 |
| | (0.21) | (0.30) |
| labor for stitching | 19.67 | 39.24 |
| | (5.25) | (12.82) |
| other labor (laminating, washing, packing, matching) | 7.32 | 15.59 |
| | (4.55) | (13.21) |
| overhead | 5.14 | 10.84 |
| | (2.05) | (6.10) |
| total | 100.00 | 210.83 |
| N | 38 | 38 |

Notes: Column 1 reports the mean cost share per ball of each input using the baseline survey. Column 2 reports the cost of each input in Rupees. Total laminated rexine is the sum of the first three components. The exchange rate is approximately Rs 100 to US$1. Standard deviations reported in parentheses.

**Table 3: Benefits from Adopting the Offset Die**

| | mean | $10^{th}$ | $25^{th}$ | $50^{th}$ | $75^{th}$ | $90^{th}$ |
|---|---|---|---|---|---|---|
| **Variable cost reduction** | | | | | | |
| rexine waste reduction (%) | 7.69 | 4.39 | 5.19 | 7.93 | 8.31 | 13.43 |
| | (0.22) | (0.46) | (0.41) | (0.30) | (0.05) | (1.18) |
| rexine as share of cost (%) | 45.94 | 34.85 | 39.87 | 44.72 | 51.22 | 55.44 |
| | (0.66) | (1.14) | (0.71) | (0.58) | (0.44) | (0.95) |
| variable cost reduction (%) | 1.17 | 0.60 | 0.80 | 1.10 | 1.37 | 1.94 |
| | (0.04) | (0.05) | (0.04) | (0.03) | (0.06) | (0.17) |
| **Variable cost increase** | | | | | | |
| cutter wage as share of cost (%) | 0.48 | 0.29 | 0.36 | 0.45 | 0.60 | 0.70 |
| | (0.01) | (0.01) | (0.00) | (0.01) | (0.01) | (0.02) |
| variable cost increase (%) | 0.08 | 0.05 | 0.06 | 0.07 | 0.10 | 0.12 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| **Net benefits** | | | | | | |
| net variable cost reduction (%) | 1.09 | 0.52 | 0.72 | 1.02 | 1.29 | 1.87 |
| | (0.04) | (0.05) | (0.03) | (0.03) | (0.06) | (0.17) |
| % net variable cost/avg % profit rate | 15.45 | 5.27 | 8.10 | 12.34 | 19.86 | 28.98 |
| | (0.71) | (0.42) | (0.50) | (0.73) | (1.21) | (2.26) |
| total cost savings per month (Rs 000s) | 174.12 | 4.46 | 12.19 | 49.38 | 165.21 | 475.01 |
| | (18.53) | (0.60) | (1.24) | (5.43) | (18.41) | (79.85) |
| days to recover fixed costs | 136.94 | 8.48 | 15.98 | 36.61 | 80.34 | 193.92 |
| | (44.52) | (0.97) | (1.68) | (2.93) | (6.50) | (15.63) |
| days to recover fixed costs (no die) | 71.10 | 4.40 | 8.30 | 19.01 | 41.71 | 100.69 |
| | (23.12) | (0.51) | (0.87) | (1.52) | (3.38) | (8.12) |

Notes: Table reports the distribution benefits from adopting the offset die. The 1st row reports the rexine waste reduction across firms, which is the percentage increase in the number of pentagons from using the offset die. The 2nd row reports laminated rexine as a share of unit costs. The 3rd row reports the variable cost reduction from adopting the offset die;. This is computed for each firm as the product of a firm's rexine waste reduction, rexine share of cost and 33 percent (an adjustment for the fact that pentagons occupy a smaller share of rexine than hexagons), and the row reports this distribution. The 4th row reports the cutter's wage as a share of unit costs. The 5th row is the variable labor cost increase percentage from adopting the offset die; this is equal to the product of the cutter share of cost, a 50 percent increase in cutting time using the offset die relative to traditional die, and 33 percent. The 6th row reports the *net* variable cost of reduction, which is the difference between a firm's variable material cost reduction and its variable labor cost increase. The 7th row reports the total cost savings per month in Rupees (the exchange rate is approximately Rs 100 to US$1). The 8th row reports the distribution of the number of days needed to recover all fixed costs of adoption. The 9th row reports the distribution of the number of days needed to recover fixed costs of adoption, excluding purchasing the die; this final row is relevant for treatment firms who received the die for free. As noted in the text, if a firm reports a missing value for one of these components, we draw a value (with replacement) from the empirical distribution within the firm's stratum. Since the late responder sample was not asked rexine share of costs (row 2) at baseline, we draw a value (with replacement) from the empirical distribution of the full sample of initial-responder firms. We repeat this process 1,000 times and report the mean across the repetitions for each percentile and the standard errors in parentheses.

Table 4: 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) | 90.7 | 0.0 | 70.0 | 85.0 | 100.0 | 100.0 | 100.0 | 100.0 | 80 |
| 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 5: Response Rates**

| | # Firms (initial responders) | | | |
|---|---|---|---|---|
| | Tech Drop | Cash Drop | No Drop | Total |
| **A. Initial responders** | | | | |
| smallest | 5 | 3 | 12 | 20 |
| medium-small | 6 | 3 | 13 | 22 |
| medium-large | 6 | 3 | 13 | 22 |
| largest | 6 | 3 | 12 | 21 |
| total | 23 | 12 | 50 | 85 |
| **B. Late responders** | | | | |
| active, late response | 12 | 5 | 14 | 31 |
| active, refused all surveys | 0 | 1 | 15 | 16 |
| inactive | 7 | 3 | 12 | 22 |
| total | 19 | 9 | 41 | 69 |

Notes: Table reports response rates, by treatment assignment, in the initial-responder sample (Panel A) and the late-responder sample (Panel B). Active firms are those who had produced soccer balls in the previous 12 months and cut their own laminated sheets.

Table 6: 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 | 1.00 | 0.83 | 0.89 |
| | (0.00) | (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 |

Notes: Table reports baseline balance for the initial-responder sample (Panel A) and the late-responder sample (Panel B). There are no significant differences across treatment assignment in the initial responder sampler. The late responder sample has significant differences across assignment which is consistent with the observation that response rates appear to have responded endogenously to treatment assignment for this sample. Standard errors reported in parentheses.

Table 7: 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) | 5 | 0 | 0 | 5 |
| # currently using new die (>1000 balls) | 5 | 0 | 0 | 5 |
| **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) | 6 | 0 | 1 | 7 |
| # currently using new die (>1000 balls) | 6 | 0 | 1 | 7 |

Notes: Table reports adoption statistics as of August 2013 in the initial-responder sample (Panel A) and the full sample (Panel B). The first three rows in each panel are the number active and responder firms. "# ever responded" is the number of firms that answered at least one of the surveys across rounds. The 4th row reports the number of firms that availed themselves of the option to trade in the 4-panel offset die for a different offset die. The discrepancy between 5th and 6th rows is that one diemaker was particularly slow in delivering an offset die and the firm subsequently canceled the order. The 7th row indicates the number of firms that ever report using the die, and the 8th row is the number of firms that were using the die (to produce at least 1,000 balls) as of August 2013.

**Table 8: 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 | 0.23** | 0.23** | | 0.56 | | | | | | 0.20*** |
| | (0.09) | (0.09) | | (0.52) | | | | | | (0.08) |
| cash drop group | | -0.00 | | | | | | | | |
| | | (0.02) | | | | | | | | |
| log avg output/month | | | 0.04 | 0.04* | | 0.04 | | | | 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 | | | | -0.45* |
| | | | | | (0.32) | (0.33) | | | | (0.26) |
| log avg price, size 5 training | | | | | | | -0.10 | | | -0.26* |
| | | | | | | | (0.07) | | | (0.13) |
| avg share promotional (of size 5) | | | | | | | | -0.09 | | -0.16 |
| | | | | | | | | (0.07) | | (0.10) |
| avg profit rate, size 5 training | | | | | | | | | 0.61 | 0.50 |
| | | | | | | | | | (0.66) | (0.65) |
| constant | 0.01 | 0.01 | -0.24 | -0.30* | 0.41 | 0.12 | 0.65 | 0.11 | 0.02 | 1.49* |
| | (0.05) | (0.05) | (0.22) | (0.18) | (0.32) | (0.45) | (0.42) | (0.07) | (0.05) | (0.75) |
| stratum dummies | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| R-squared | 0.22 | 0.22 | 0.07 | 0.25 | 0.11 | 0.13 | 0.07 | 0.06 | 0.07 | 0.36 |
| N | 79 | 79 | 79 | 79 | 74 | 74 | 68 | 79 | 66 | 63 |

Notes: Table reports linear probability regressions of technology adoption, measured as current use, on firm characteristics for the initial-responder sample. Variables beginning with "avg. ..." represent within-firm averages across all rounds for which responses are available. All regressions include stratum dummies. Significance: * .10; ** .05; *** 0.01.

**Table 9: 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) | (10) | (11) |
| tech drop group | 0.23** | | | | | | | | | | 0.28** |
| | (0.09) | | | | | | | | | | (0.11) |
| CEO university indicator | | 0.00 | | | | | | | | | -0.03 |
| | | (0.08) | | | | | | | | | (0.08) |
| CEO experience (/100) | | | -0.25 | | | | | | | | -0.11 |
| | | | (0.17) | | | | | | | | (0.30) |
| age of firm (/100) | | | | -0.10 | | | | | | | -0.01 |
| | | | | (0.10) | | | | | | | (0.15) |
| cutters paid piece rate | | | | | 0.03 | | | | | | -0.06 |
| | | | | | (0.03) | | | | | | (0.05) |
| Rs/ball, head cutter | | | | | | 0.10 | | | | | |
| | | | | | | (0.15) | | | | | |
| head cutter experience (/100) | | | | | | | -0.14 | | | | |
| | | | | | | | (0.19) | | | | |
| head cutter tenure (/100) | | | | | | | | 0.03 | | | |
| | | | | | | | | (0.33) | | | |
| cutter raven's score | | | | | | | | | -0.01 | | |
| | | | | | | | | | (0.03) | | |
| avg pent/sheet, rescaled (/100) | | | | | | | | | | 0.76* | -0.10 |
| | | | | | | | | | | (0.39) | (0.48) |
| log avg output/month | | | | | | | | | | | 0.05 |
| | | | | | | | | | | | (0.04) |
| constant | 0.01 | 0.06 | 0.11 | 0.08 | 0.03 | -0.10 | 0.02 | -0.00 | 0.03 | -1.86* | -0.09 |
| | (0.05) | (0.05) | (0.07) | (0.06) | (0.04) | (0.19) | (0.03) | (0.04) | (0.07) | (0.96) | (1.06) |
| stratum dummies | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| R-squared | 0.22 | 0.05 | 0.06 | 0.06 | 0.06 | 0.07 | 0.06 | 0.06 | 0.11 | 0.09 | 0.30 |
| N | 79 | 70 | 77 | 78 | 75 | 74 | 33 | 32 | 37 | 70 | 56 |

Notes: Table reports linear probability regressions of technology adoption, measured as current use, on manager and cutter characteristics for the initial-responder sample. "Cutters paid piece rate" is an indicator of if the cutter is paid a piece rate. "Rs/ball, head cutter" is the rupee payment per ball to the head cutter. Variables beginning with "avg. ..." represent within-firm averages across all rounds for which responses are available. All regressions include stratum dummies. Significance: * .10; ** .05; *** 0.01.

**Table 10: 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 |

Notes: Table reports responses of 18 tech-drop firms from the March-April 2013 survey round.

**Table 11: Baseline Balance in Incentive-Payment Experiment**

| | Group A Incentive Contract | Group B No Incentive 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 |

Notes: Table reports baseline balance in the Incentive-Payment Experiment. This sample is the 31 tech-drop firms from the Tech-Drop Experiment who were active as of September 2013. There are no statistical difference between treatment and control groups. Standard errors reported in parentheses.

**Table 12: "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 |

Notes: Table reports the times achieved by cutters at the 10 Group A firms who agreed to the incentive payment intervention. The 2nd row reports the time, in minutes, to cut a single rexine sheet with the offset die. The 3rd row reports the size of the die (in mm) used by the cutter. The 4th row reports the number of pentagons achieved. Note that the average time to cut with the traditional die is 2:15.

**Table 13: 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 | | 0.48*** | | 0.48*** | | 0.59*** | | 0.63*** |
| | | (0.15) | | (0.15) | | (0.18) | | (0.18) |
| assigned to group A | 0.68*** | | 0.32** | | 0.62*** | | 0.38*** | |
| | (0.12) | | (0.12) | | (0.14) | | (0.13) | |
| stratum dummies | Y | Y | Y | Y | Y | Y | Y | Y |
| R-squared | 0.57 | 0.69 | 0.60 | 0.69 | 0.50 | 0.57 | 0.36 | 0.57 |
| N | 31 | 31 | 31 | 31 | 26 | 26 | 26 | 26 |

Notes: Table reports results of incentive-payment experiment on adoption rates using current use as the measure of adoption. The left panel includes all firms. For this sample, the p-value testing the null hypothesis that treatment has no effect in the ITT specification using 25,872,000 possible permutations of treatment assignment is 3.04 percent. The right panel includes only initial non-adopter firms. For this sample, the corresponding p-value from the possible 1,293,600 permutations is 3.04 percent. All regressions include stratum dummies. Significance: * .10; ** .05; *** 0.01.

**Table 14: Incentive-Payment Experiment Results (Die Purchase as Outcome)**

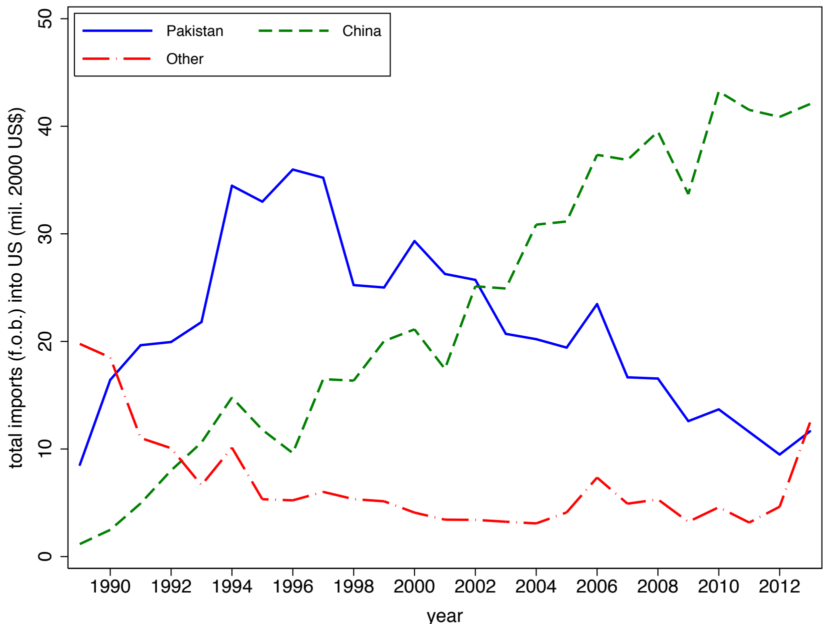
| | Dep. var.: purchased first offset die (beyond trade-in) after Sept. 1, 2013 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | All Strata | | | | Initial Non-Adopters | | | |
| | First Stage (1) | OLS (2) | Reduced Form (ITT) (3) | IV (TOT) (4) | First Stage (5) | OLS (6) | Reduced Form (ITT) (7) | IV (TOT) (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 |

Notes: Table reports results of incentive-payment experiment on adoption rates using additional die purchases (beyond the trade-in offer) after September 2013 as the measure of adoption. he left panel includes all firms. For this sample, the p-value testing the null hypothesis that treatment has no effect in the ITT specification using 25,872,000 possible permutations of treatment assignment is 4.28 percent. The right panel includes only initial non-adopter firms. For this sample, the corresponding p-value from the possible 1,293,600 permutations is 21.42 percent. All regressions include stratum dummies. Significance: * .10; ** .05; *** 0.01. All regressions include stratum dummies. Significance: * .10; ** .05; *** 0.01.

Figure 1: "Buckyball" Design

Notes: Figure shows the standard soccer ball "buckyball" design. It combines 20 hexagons and 12 pentagons.

Figure 2: U.S. Imports of Inflatable Soccer Balls




Notes: Figure shows import market share within the United States in HS 10-digit category 9506.62.40.80 ("inflatable soccer balls"). Source: United States customs data.

Figure 3: Making the Laminated Sheet (Step 1)

Notes: Figure displays workers laminating a rexine sheet, which is the first stage of producing a soccer ball. Layers of cloth (cotton and/or polyester) are glued to artificial leather called rexine using a latex-based adhesive to form the laminated sheet.

Figure 4: Cutting the Laminated Sheet (Step 2)

Notes: Figure displays a cutter using a hydraulic press to cut hexagons and pentagons from the laminated sheet.

Figure 5: Printing the Designs (Step 3)

Notes: Figure displays a worker printing a logo on the pentagon and hexagon panels.

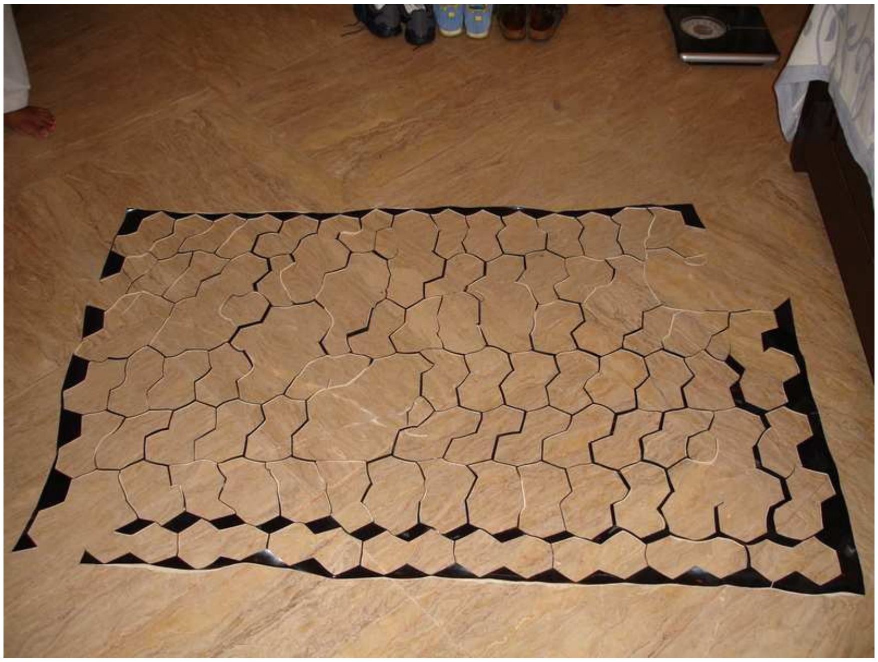
Figure 6: Stitching (Step 4)

Notes: Figure displays a worker stitching a soccer ball. Source: Der Spiegel.

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

Notes: Figure displays the traditional two-panel hexagon and pentagon dies.

Figure 8: Laminated Sheet Wastage from Cutting Hexagons

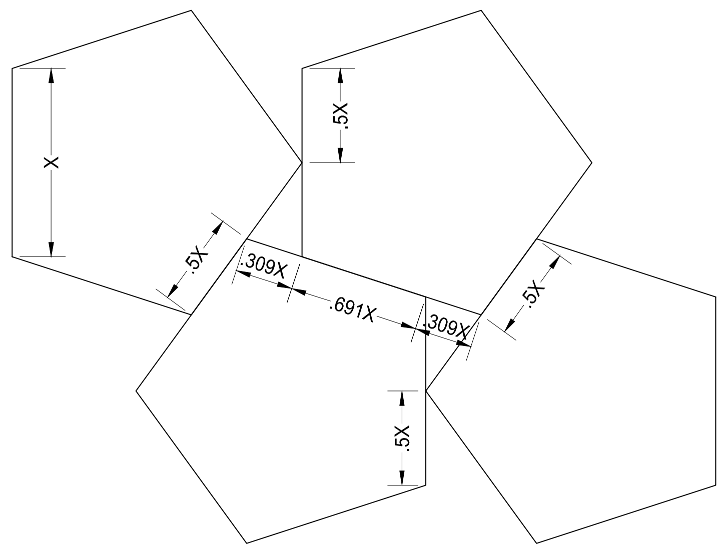


Notes: Figure displays laminated rexine wastage from cutting hexagons with the traditional die.

Figure 9: Laminated Sheet Wastage from Cutting Pentagons

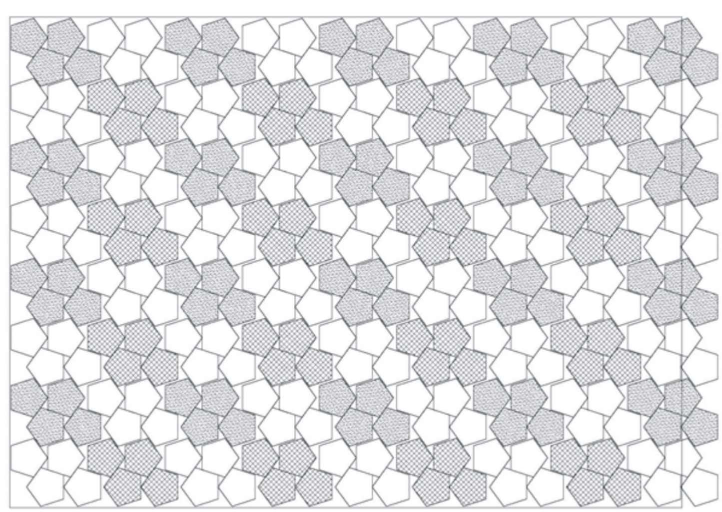
Notes: Figure displays laminated rexine wastage from cutting pentagons with the traditional die.

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



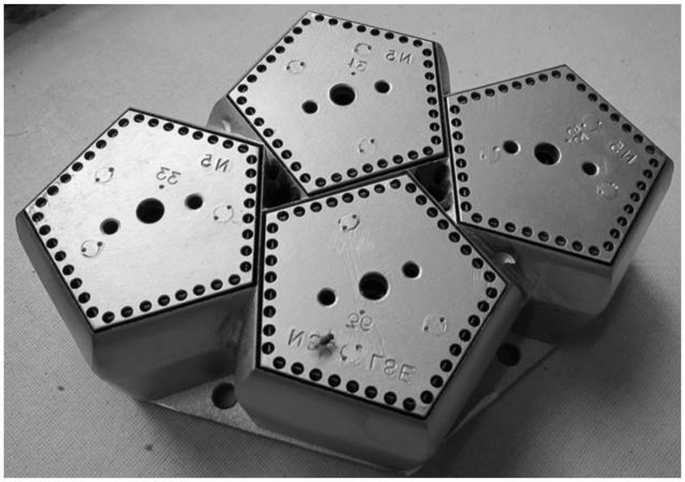

Notes: Figure displays blueprint of the four-panel offset die that was provided to Tech-Drop firms.

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



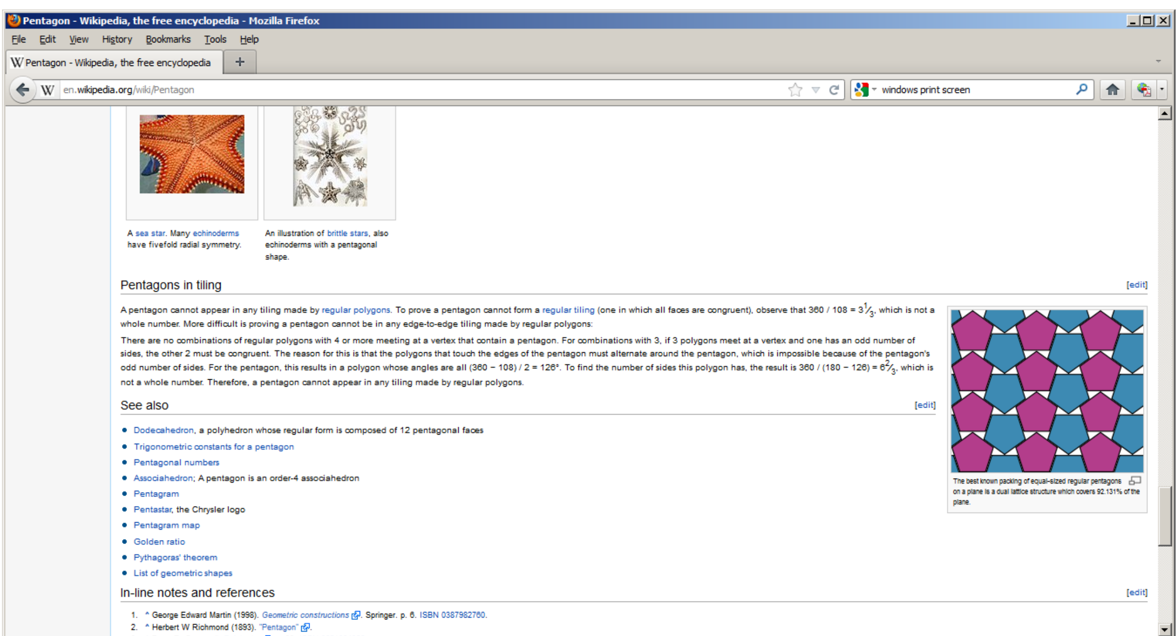
Notes: Figure displays the cutting pattern for the four-panel offset die.

Figure 12: The "Offset" Four-Pentagon Die



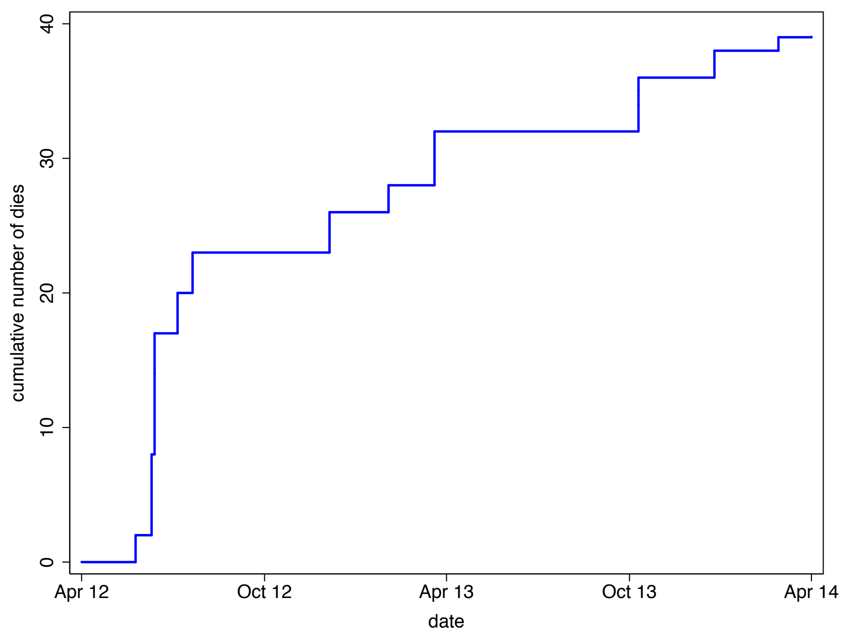
Notes: Figure displays the four-panel offset die that was provided to Tech-Drop firms.

Figure 13: Wikipedia "Pentagon" Page



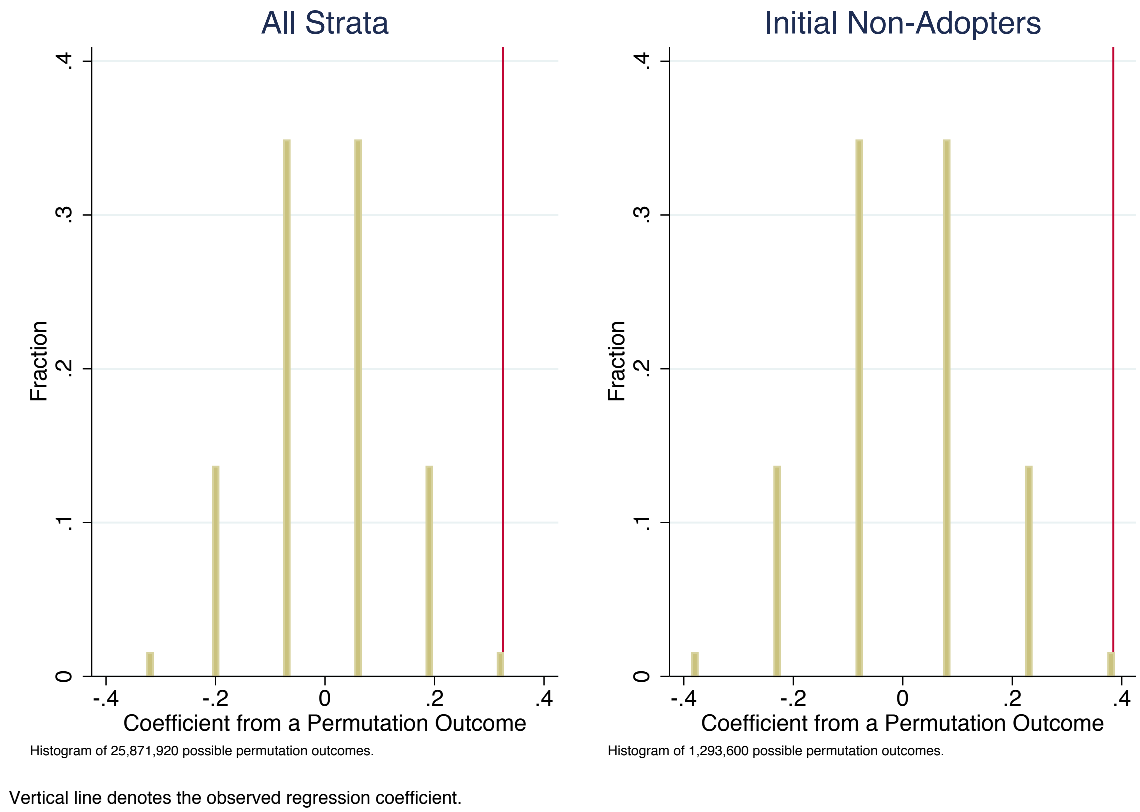

Notes: Figure displays the Wikipedia "Pentagon" page. Accessed April 29, 2012.

Figure 14: Adoption of Offset Dies by Firm Z



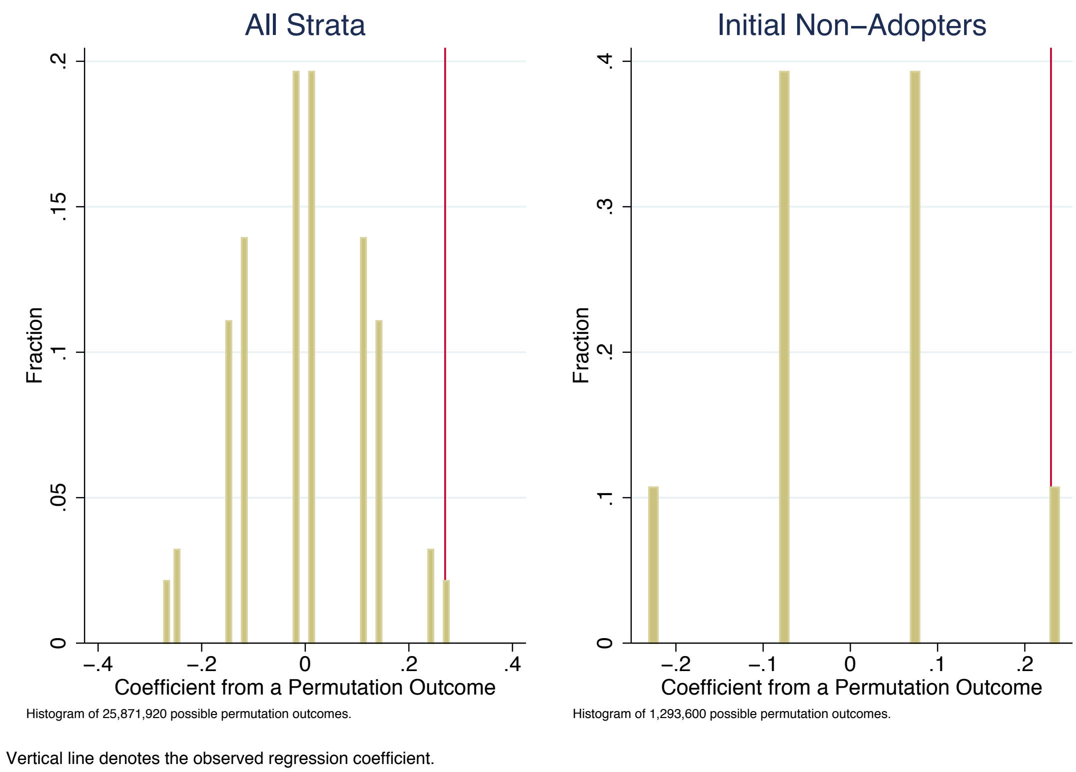

Notes: Figure displays the cumulative die purchases by Firm Z.

Figure 15: Permutation Outcomes: Current Use




Notes: Figure displays the distribution of outcomes from the permutation tests using current die use as the measure of adoption. The left panel reports outcomes from the specification that includes all firms. The right panel reports outcomes from the specification that includes initial non-adopters only.

Figure 16: Permutation Outcomes: Die Purchase




Notes: Figure displays the distribution of outcomes from the permutation tests using die purchases as the measure of adoption. The left panel reports outcomes from the specification that includes all firms. The right panel reports outcomes from the specification that includes initial non-adopters only.

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 | 0.84 | |
| 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 | 90.00 | 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.

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