ORGANIZATIONAL BARRIERS TO TECHNOLOGY ADOPTION:
EVIDENCE FROM SOCCER-BALL PRODUCERS IN PAKISTAN

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ABSTRACT

This paper studies technology adoption in a cluster of soccer-ball producers in Sialkot, Pakistan. We invented a new cutting technology that reduces waste of the primary raw material and gave the technology to a random subset of producers. Despite the arguably unambiguous net benefits of the technology for nearly all firms, after 15 months take-up remained puzzlingly low. We hypothesize that an important 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 that originally received the technology: we offered one cutter and one printer per firm a lump-sum payment, approximately equal to a monthly wage, 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

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 have focused on agriculture or medicine,[2] but diffusion has also been observed to be slow among large firms in manufacturing. In a classic study of major industrial technologies, Mansfield (1961) 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, technologies that were eventually adopted by all major firms.[3] More recently, Bloom, Eifert, Mahajan, McKenzie, and Roberts (2013) found that many Indian textile firms are not using standard (and apparently cheap to implement) management practices that have diffused widely elsewhere. The surveys by Hall and Khan (2003) and Hall (2005) contain many more examples.

Why is adoption so slow for so many technologies? The question is key to understanding the process of economic development and growth. It is also a difficult one to study empirically, especially among manufacturing firms. It is rare to be able to observe firms' technology use directly, and rarer still to have direct measures of the costs and benefits of adoption, or of what information firms have about a given technology. 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 is economically significant, producing 30 million soccer balls per year, including for the largest global brands. 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, using largely the same, simple production process. The technology we focus on is 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 nearly all firms in the sector. 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 densest packing of pentagons in a plane known to mathematicians. A conservative estimate is that the new die reduces rexine cost per pentagon by 6.84 percent and reduces total costs by approximately 1 percent — a modest reduction

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[1]In a well-cited review article, Geroski (2000, p.604) writes: "The central feature of most discussions of technology diffusion is the apparently slow speed at which firms adopt new technologies." Perhaps the foremost economic historian of technology, Nathan Rosenberg, writes "[I]f one examines the history of the diffusion of many inventions, one cannot help being struck by two characteristics of the diffusion process: its apparent overall slowness on the one hand and the wide variations in the rates of acceptance of different inventions on the other" (Rosenberg (1972, p. 6)).

[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 also the summary in Table 2 of Mansfield (1989).

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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. Importantly, we observe adoption of the new die very accurately, in contrast to studies that infer technology adoption from changes in residual-based measures of 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 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; we are pursuing this line of inquiry in a companion project. 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.[4] 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 40 dies on 15 separate occasions. Overall, however, adoption remained puzzlingly low.

In our March-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 resistance from cutters. Anecdotal evidence from a number of firms we visited also suggested that workers were resisting the new die, including by misinforming owners about the productivity benefits of the die. Moreover, we noticed that the large adopter (purchaser of the 40 dies) differed from the local norm 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 evidence 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 falls 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 resist adoption. We formalize this intuition in a simple model of strategic communication between an imperfectly informed principal and a perfectly informed agent within a firm. When firms are limited to standard piece-rate contracts that must be set ex-ante, 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.[5] A relatively simple modification to the labor contract, conditioning

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[4]In this introduction, we use our "liberal" measure of adoption; see Section 4 below for a discussion of our "liberal" and "conservative" adoption measures.

[5]We argue below, following Crawford and Sobel (1982), that this equilibrium is a particularly salient one, because it is the "most informative" among all possible equilibria.

the wage contract on marginal cost, an ex-post-revealed characteristic of the technology, induces the agent to truthfully reveal the technology and the principal to adopt it.

To investigate the misalignment-of-incentives hypothesis, we designed and implemented a second experiment. In September 2013, we randomly divided the set of 31 tech-drop firms that were still in business into two subgroups, a treatment subgroup (which we call Group A) and a control subgroup (Group B). To Group B, we simply gave a reminder about the benefits of the die and an offer of another demonstration of the cutting pattern. To Group A, we gave the reminder but also explained the issue of misaligned incentives to the owner and offered an incentive-payment treatment: we offered to pay one cutter and one printer a lump-sum bonus roughly equivalent to a monthly wage (US$150 and US$120, respectively), conditional on demonstrating competence with the new technology in the presence of the owner within one month. This bonus was designed to mimic (as closely as possible, given firms' reluctance to participate) the modified "conditional" wage contracts we model in the theory. The one-time bonus payments were small relative both to revenues from soccer-ball sales for the firms, approximately US$57,000 per month at the median, and to the variable cost reductions from adopting of our technology, which we estimate to be approximately US$454 per month at the median.

Fifteen firms were assigned to Group A and 16 to Group B. Of the 13 Group A firms that had not already adopted the new die, 8 accepted the incentive-payment intervention, and five adopted the new die within six months of the second experiment. Of the 13 Group B firms that had not already adopted the new die, none adopted within six months of the experiment and one adopted in the next six-month period. Although the sample size is small, the positive effect on adoption is statistically significant, with the probability of adoption increasing by 0.27-0.32 from a baseline adoption rate of 0.13 in our intent-to-treat specifications. Our baseline results remain significant when using permutation tests that are robust to small sample sizes. The fact that such small payments had a significant effect on adoption suggests that the misalignment of incentives is indeed an important barrier to adoption in this setting.

After the second experiment, we asked owners and their employees a number of survey questions about wage setting and communication within the firm, and the results are supportive of the hypothesis that piece-rate contracts are sticky and that cutters have misinformed owners about the technology, consistent with our theoretical model. We argue that the results do not support a leading alternative hypothesis, that our second experiment mechanically induced adoption by subsidizing the fixed costs of adoption, because such a hypothesis cannot quantitatively explain both low initial adoption rates and an increase in adoption of the magnitude we find in response to our second experiment. We also argue against the hypothesis that our second experiment merely increased the salience of the technology to owners, and that this alone led to increased adoption.

A natural question 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 or desirable, just as the technical innovation had not occurred to them. The second is that there

is a transaction cost involved in changing payment schemes that exceeds the expected benefits. In Section 8 below we present several pieces of evidence to suggest that the costs of modifying contracts are substantial, in part because of local norms. In the end, the two hypotheses have similar observable implications and are difficult to distinguish empirically. But the important point for our study 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 an effect on adoption.

In addition to the research cited above, our paper is related to several different strands of literature. A number of studies have highlighted resistance to adopting new technologies in manufacturing. Lazonick (1979) and Mokyr (1990) argue that guilds and trade unions slowed implementation of new technologies during the industrial revolution. Similarly, Parente and Prescott (1999) argue that market power of factor suppliers can explain low levels of adoption. Historically, many cases are of resistance to labor-saving technologies that could substitute for the labor of skilled artisans. Focusing on more recent periods, Bloom and Van Reenen (2007, 2010) and Bloom et al. (2013) suggest that a lack of product-market competition may be responsible to the failure to adopt beneficial management practices. Another literature emphasizes that new technologies often require changes in complementary technologies, which take time to implement (Rosenberg, 1982; David, 1990; Bresnahan and Trajtenberg, 1995). In our setting, unions are absent, our technology is labor-*using* rather than labor-saving, firms sell almost all output on international export markets that appear to be quite competitive, and our technology requires extremely modest changes to other aspects of production, so the most common existing explanations do not appear to be directly applicable. We view our focus on intra-organizational barriers as complementary to these literatures.

Our paper is related to an active literature on technology adoption in non-manufacturing settings in developing countries. Much of this work has focused on agriculture, where clean measures of technology use are more often available than in manufacturing (e.g. Foster and Rosenzweig (1995), Munshi (2004), Bandiera and Rasul (2006), Conley and Udry (2010), Duflo, Kremer, and Robinson (2011), Suri (2011), Hanna, Mullainathan, and Schwartzstein (2014), BenYishay and Mobarak (2014), Beaman, Ben-Yishay, Magruder, and Mobarak (2015)). We believe that manufacturing firms are important in their own right, as their decisions clearly matter for development and growth. They also raise issues of organizational conflict that do not arise when the decision-makers are individual smallholder farmers.[6] In addition, risk arguably plays a less important role among manufacturing firms, both because there is a lower degree of production risk (making inference about a technology easier) and because factory owners are typically richer and presumably less risk-averse than small-holder farmers.

Our paper is also related to a small but growing literature on field experiments in firms, including the experiments with fruit-pickers by Bandiera, Barankay, and Rasul (2005, 2007, 2009), with small retailers by de Mel, McKenzie, and Woodruff (2008), and with Indian textile firms

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[6]Also related are recent papers on adoption of health technologies in the presence of externalities (Miguel and Kremer, 2004; Cohen and Dupas, 2010; Dupas, 2014) and on the effect of informational interventions on change-holding behavior of Kenyan retail micro-enterprises (Beaman, Magruder, and Robinson, 2014). As in the literature on agriculture, organizational conflict does not play an important role in these settings.

(mentioned above) by Bloom et al. (2013).[7] In addition to emphasizing 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 a conflict of interest within firms can impede the flow of information to managers and provides a possible micro-foundation for such informational constraints.[8]

The theoretical model we develop draws on ideas from two strands of theoretical research: the literature on strategic communication following Crawford and Sobel (1982) and the voluminous literature on principal-agent models of the employment relationship (reviewed for instance by Lazear and Oyer (2013) and Gibbons and Roberts (2013)). Lazear (1986) and Gibbons (1987) formalize the argument that workers paid piece rates may hide information about labor-saving productivity improvements from their employers, to prevent employers from reducing rates.[9] 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. Stole and Zwiebel (1996) model the idea that owners may not adopt technically efficient technologies if they weaken their position in intra-firm bargaining. Our study supports the argument of Milgrom and Roberts (1995) that piece rates may need to be combined with other incentives (in our case higher pay conditional on adopting the new technology) in order to achieve high performance. Also related are Dearden, Ickes, and Samuelson (1990), Zwiebel (1995), Aghion and Tirole (1997), Dessein (2002) and Krishna and Morgan (2008). We view our model primarily as an application of ideas from these literatures to our setting, although we are not aware of a theoretical treatment of the specific idea that piece-rate contracts (and frictions in making adjustments to them) can induce workers to misinform owners about labor-using but on-net-beneficial technologies.[10]

The paper is organized as follows. Section 2 provides background on the Sialkot cluster. Section 3 describes the new cutting technology. Section 4 describes our surveys and presents summary statistics. Section 5 details the roll-out of the new technology and documents rates of early adoption. Section 6 discusses qualitative evidence on organizational barriers 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 presents additional evidence on the hypothesized theoretical mechanisms. Section 9 considers the leading alternative interpretations of our findings, and Section 10 concludes.

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[7]See Bandiera, Barankay, and Rasul (2011) for a review of the literature on field experiments in firms.

[8]In other related work, Anderson and Newell (2004) study the effect of information from energy-efficiency audits on U.S. firms' adoption decisions in a non-experimental setting (but do not focus on organizational barriers). The "insider econometrics" literature reviewed by Ichniowski and Shaw (2013) focuses on relationships between management practices and productivity, typically in a cross-sectional context, and generally does not focus on technology adoption. A recent experimental study by Khwaja, Olken, and Khan (2014) is in a different setting (the Punjab tax department), but focuses on a similar issue: the effect of altering wage contracts on employee performance.

[9]Descriptive evidence on intra-organizational conflicts over piece rates is provided by the classic studies of Edwards (1979) and Clawson (1980).

[10]Perhaps the closest precursor to this idea is a case study by Freeman and Kleiner (2005), who provide descriptive evidence that an American shoe company's shift away from piece rates helped it to increase productivity.

2 Industry Background

Sialkot, Pakistan is a city of 1.6 million people in the province of Punjab. The soccer-ball cluster dates to British colonial rule. In 1889, a British sergeant asked a Sialkoti saddle-maker first to repair a damaged ball, and then to make a new ball made from scratch.[11] The industry 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. In 1982, a firm in Sialkot manufactured the FIFA World Cup ball for the first time. Virtually all of Pakistan's soccer ball production is both concentrated in Sialkot and exported to foreign markets. While in recent years the industry has faced increasing competition from East Asian, especially Chinese, suppliers,[12] Sialkot 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.[13]

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 estimated to be more than twice that number (Khan, Munir, and Willmott, 2007). The largest firms have hundreds of employees and produce for international brands such as Nike and Adidas as well as smaller brands. These firms manufacture both high-quality "match" and medium-quality "training" balls, often with a brand or team logo, as well as lower quality "promotional" balls, often branded with an advertiser's logo. The remaining producers are small- and medium-size firms (the median firm size is 25 employees) which typically produce promotional balls either for clients they meet through industry fairs and online markets or under subcontract to larger firms.

3 The New Technology

3.1 Production process

Before presenting our new technology, we 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.[14] There are four stages of production. In the first stage, shown in Figure 2, 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 rexine sheet (henceforth "laminated rexine"). 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 higher-quality rexine, which tends to be imported, is used). In the second stage, shown in Figure 3, a skilled cutter uses a metal die and a hydraulic press to cut the hexagonal and pentagonal panels from the laminated rexine. The cutter

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

[12]The evolution of soccer-ball imports to the U.S. (which tracks soccer balls specifically, unlike other major importers) is shown in Appendix Figure A.1.

[13]The ball for the 2014 World Cup, also produced in Sialkot, uses a new thermo-molding technology.

[14]The buckyball design is based on a geodesic dome designed by R. Buckminster Fuller.

positions the die by hand before activating the press with a foot-pedal. He then slides the rexine along and places the die again to make the next cut.[15] In the third stage, shown in Figure 4, logos or other insignia are printed on the panels. This requires a "screen," held in a wooden frame, that allows ink to pass through to create the desired design. Typically the dies cut pairs of hexagons or pentagons, making an indentation between them but leaving them attached to be printed as a pair, using one swipe of ink. In the fourth stage, shown in Figure 5, the panels are stitched together around an inflatable bladder. Unlike the previous three stages, this stage is often outsourced, to specialized stitching centers or stitcher's homes. This stage is the most labor-intensive part of the production process, accounting for approximately 71 percent of total labor costs.

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 or full laminated rexine sheets 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 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 with the panels sharing an entire edge (Figure 6). 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 rexine sheet, mostly around the edges. (See the laminated rexine "net" remaining after cutting hexagons in Figure 7.) By contrast, pentagons do not tessellate, and using the traditional two-pentagon die even experienced cutters typically waste 20-24 percent of the laminated rexine sheet (Figure 8). The leftover laminated rexine has little value; typically it is sold to brickmakers who burn it to fire their kilns.

3.2 The innovation

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 in 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 (Figure 9). Based on the pattern in the video, Verhoogen and Annalisa Guzzini, an architect (who is also his wife), developed a blueprint for a four-pentagon die (Figures 10 and 11). Through an intermediary, we contracted with a diemaker in Sialkot to produce the die (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. The pattern appeared in a

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[15]We use "he" since all of the cutters, printers and owners we have encountered have been men.

1990 paper in *Discrete & Computational Geometry* (Kuperberg and Kuperberg, 1990).[16] It also appears, conveniently enough, on the Wikipedia "Pentagon" page (Figure 13).

The pentagons in the new die are offset, with the two leftmost pentagons sharing half an edge, rather than a full edge. We refer to the new die as the "offset" die, and treat other dies with pentagons sharing half an edge as variations on our technology.[17] A two-pentagon variant of our design can be made using the specifications in the blueprint (with the two leftmost and two rightmost pentagons in Figure 11 cut separately). This version is easier to maneuver with one hand and can be used with the same cutting rhythm as the traditional two-pentagon die; it is the version that has proven more popular with firms.

3.3   Benefits and costs

In order to quantify the various components of benefits and costs of using the offset die, we draw on several rounds of survey data that we describe in more detail in Section 4 below. We start by comparing the number of pentagons per sheet typically cut using the traditional die with the number using the offset die. The dimensions of pentagons and hexagons vary slightly across orders, even for balls of a given official size (e.g. size 5, the standard size for adults), depending on the thickness and quality of the laminated rexine sheet used. 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 laminated 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 reports direct observations by our survey team, during the implementation of our first experiment. In the fifth row, we have multiplied the raw measures by the ratio of means for size 44 mm and the corresponding size; the rescaled measure provides an estimate of the number of pentagons per sheet the firm would obtain using a 44 mm die. The owner reports and direct observations correspond reasonably closely, with owners slightly overestimating pentagons per sheet relative to our direct observations. Both measures suggest that cutters obtain approximately 250 pentagons per sheet using the traditional die.

Using the offset die and cutting 44 mm pentagons, it is possible to achieve 272 pentagons per sheet, as illustrated in Figure 10.[18] For 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

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[16]The cutting pattern represents the densest 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.

[17]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 10) and was planning to implement it on a new large cutting press to cut half a laminated 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.

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

the offset die. As discussed in more detail below, relatively few firms have adopted the offset die, and therefore we have few observations. But even keeping in mind this caveat, we can say with a high level of confidence that more pentagons can be obtained per sheet using the offset die. The directly observed mean is 275.4, 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.

In order to convert these figures 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.[19] The table shows that the laminated rexine (rexine plus cotton/polyester plus latex) 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. In the second column, we report the input cost in rupees; the mean cost of a two-layer promotional ball is Rs 211 (US$2.11).[20]

The cost savings from the offset die vary across firms, depending in part on 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, training and match balls. 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 in the baseline survey, and only a subset of firms have adopted the offset die. To compute the distributions, 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 size stratum.[21] We repeat this procedure 1,000 times and report the means and standard deviations from the procedure at various percentiles of the distribution of each variable.

In Row 1 of Table 3, we report the distribution of the percentage reduction in the cost of laminated rexine used to cut pentagons when moving to the offset die. The pentagon cost reduction is 6.84 percent at the median and ranges from 4.18 percent at the 10th percentile to 11.23 percent at the 90th percentile. Combining these figures with the laminated rexine share of total unit costs (which has the distribution reported in Row 2) and multiplying by 33 percent (the share of pentagons in total laminated rexine costs, since a standard ball uses more hexagons than pentagons and the hexagons are bigger) yields the percentage reduction in variable material costs reported in Row 3. The reduction in variable material costs is 0.98 percent at the median and ranges from 0.58 percent at the 10th percentile to 1.67 percent at the 90th percentile.[22]

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[19]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.

[20]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.

[21]As discussed below, in our first experiment firms were stratified according to total monthly output (measured in number of balls) at baseline. One stratum (the "late-responder" stratum) is composed of firms that did not respond to the baseline survey. Because information on laminated rexine shares was collected only at baseline, we draw laminated rexine shares for late responders from the empirical distribution that pools the other strata. (We do not pool for the other variables, for which we have information on the late responders from later rounds.)

[22]Note that because a firm at a given percentile of the distribution of rexine cost reductions is not necessarily

The offset die requires cutters to be more careful in the placement of the die when cutting, at least while they are learning how to use it. A conservative estimate of the increase in labor time for cutters (for the preferred two-pentagon variant) is 50 percent.[23] (In Section 7.2 below we discuss why the 50 percent number is conservative.) If firms compensate workers for this extra labor time, labor costs will increase. 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.[24] Multiplying the cutter share by 33 percent (assuming that pentagons take up one third of cutting time, equivalent to their share of laminated rexine cost) and then by 50 percent (our conservative estimate of the increase in labor time) yields the percentage increase in variable labor costs from adopting the offset die if the firms were to compensate workers (Row 5).

Although the proportional increase in cutting time is potentially large, the cutter's share of costs is sufficiently low that the variable labor cost increase is very small. Row 6 reports the *net* variable cost reduction, the difference between the variable materials cost reduction and the variable labor cost increase. The net variable cost reduction is 0.90 percent at the median, and ranges from 0.49 percent at the 10th percentile to 1.60 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 the industry: 8.39 percent at the median and 8.42 percent at the mean.[25] Row 7 shows the ratio of the net variable cost reductions to average profits; the mean and median ratios are 14.11 percent and 11.33 percent, respectively. 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 and median monthly cost savings are Rs 147,940 (US$1,479) and Rs 45,360 (US$454), respectively, and savings range from Rs 3,960 (US$40) at the 10th percentile to Rs 415,530 (US$4,155) at the 90th percentile.

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. The market price for a two-pentagon offset die is approximately Rs 10,000 ($100).[26] As we explain below, we paid this fixed cost for the firms in the tech-drop group. The offset die requires few changes to other aspects of the production process, since the pentagons that it cuts are identical to the pentagons cut by the traditional die, but there are two adjustments that many firms make, related to the fact

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the same as the firm at that percentile of the distribution of rexine as a share of cost, the numbers should not be multiplied across rows for a particular percentile.

[23] As noted above, the two-pentagon version of the offset die has proven more popular with firms. As discussed in more detail in Section 5 below, we offered firms the ability to trade in the four-pentagon die, and all firms that traded in requested the two-pentagon version. This suggests that any potential speed benefits from cutting four pentagons at a time with the four-pentagon die are negated by the fact it is more difficult to maneuver.

[24] The cutter wage as a share of costs reported here is lower than in Table 2 because that table reports input components as a share of the cost of a promotional ball. In Table 3, we explicitly account for firms' product mixes across promotional, training and match balls. To get the firm's average ball cost, we divide its reported price by one plus its reported profit margin for each ball type and then construct a weighted-average unit cost using output weights for each type. The cutter share of cost is calculated as the per-ball payment divided by this weighted-average unit cost.

[25] 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.

[26] We were initially charged Rs 30,000 (US$300) for a four-piece die.

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that pairs of pentagons cut by the offset die remain attached in a different way (i.e. sharing half an edge) than those cut by the traditional die. First, for balls with printed pentagons the printing screens must be re-designed and re-made to match the offset pattern. Designers typically charge Rs 600 (US\$6) for a new design; for the minority of firms that do not have in-house screenmaking capabilities, a new screen costs Rs 200 (US\$2) from an outside screenmaker. (New screens must in any case be made for any new order but we include them to be conservative.) Second, some firms use a "combing" machine, a device to enlarge the holes at the edges of panels made by the cutting die to further facilitate sewing. These machines also use dies. A two-pentagon combing die that works with pentagons cut by the two-pentagon offset die costs approximately Rs 10,000 (US\$100). For both printing and combing, it is always possible to cut and work with separate pentagons, but there is a speed benefit to keeping the pairs of pentagons attached. Adding together the cost of the die, the cost of a new screen design and screen, and a new combing die, a conservative estimate of total fixed costs of adoption is Rs 20,800 (US\$208).

A common way for firms to make calculations about the desirability of adoption is to use a rule of thumb (or "hurdle") for the length of time required to recoup the fixed costs of adoption (the "payback period"). Reviewing a variety of studies from the U.S. and U.K., Lefley (1996) reports that the "hurdles" vary from 2-4 years, with the mean at approximately 3 years.[27] The final two rows of Table 3 report the distribution of the number of *days* needed to recover the fixed costs of adoption detailed above. For this calculation, we calculate output per cutter per month and hence the cost savings per cutter per month. Dividing our conservative estimate of per-cutter fixed costs (assuming that each cutter needs his own offset die and combing die) 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 39 days; the payback period ranges from 9 days at the 10th percentile to 207 days at the 90th percentile (which corresponds to firms that 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 row is relevant for the tech-drop firms, to which we gave dies at no cost. In this scenario, the median time to recover fixed costs is only 20 days, and three-quarters of firms can recover the fixed costs within approximately six weeks. In short, the available evidence indicates that for almost all firms, assuming that they are not extraordinarily myopic, there are clear net benefits to adopting the offset die.

4   Data and Summary Statistics

Between September and November 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 rexine. Of the 157 firms on our initial list, we subsequently discovered that 22 were not active by our definition. Of the remaining 135 firms, 3 served as pilot firms for testing our technology.

We carried out a baseline survey between January and June 2012. Of the 132 active non-pilot

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[27]Using data from energy-efficiency audits in the U.S., Anderson and Newell (2004) infer that firms are using hurdles of 1-2 years.

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.[28] 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 responders to 116. The baseline survey 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: July 2012, October 2012, January 2013, March-April 2013, September-November 2013, January-March 2014, and October-December 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. In tech-drop 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, by probing indirectly about changes in the factory. In addition, we have obtained reports of sales of the offset dies from the six diemakers operating in Sialkot. We have detailed information on the dates firms have ordered offset dies from the diemakers, the dates the diemakers have delivered the dies, and the numbers of offset dies purchased. 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.

We face three important choices about how to measure adoption. One is whether to impose a lower bound on the number of balls produced with the offset die. Several firms have reported that they have experimented with the die but have 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 the same counts of adopters. A second decision we face is how to deal with the volatility of orders and output in the industry. Many of the smaller and medium-sized firms have large orders some months and no orders in others. In addition, a particular offset die may not be useful on all orders. Ball designs and pentagon/hexagon sizes requested by clients vary, and clients have been known to request that firms use exactly the same dies as on previous orders. For these reasons, we consider the number of balls ever produced (rather than produced in the last month) when constructing the adoption measure. The third choice we face is whether to use information we gained from firms outside of the formal survey process. Because we have been concerned about recall bias over periods of more than month, our surveys have asked firms about their production in the previous month. However, our project team has been in regular, ongoing contact with firms, including between survey rounds, and has submitted field notes that summarize these interactions. In one case in particular, the firm told our enumerators that it had produced more than 1,000 balls using the offset die, but that order did not happen to fall in the month preceding a survey response. To address this issue, we construct two measures of adoption: a "conservative" measure that classifies adoption using only

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[28]In the mid-1990s, there was a child-labor scandal in the industry in Sialkot. Firm owners were initially quite distrustful of us in part for that reason.

survey data, and a "liberal" measure that classifies adoption using both survey data and field reports. Our preferred measure uses the liberal definition because it incorporates all the information we have regarding firms' activities, but we report results for both measures.

Table 4 presents summary statistics on various firm characteristics, including means and values at several quantiles. Panel A reports statistics for the sample of 85 initial 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 where we have more complete data, a number of facts are worth emphasizing. The median firm is medium-size (18.3 employees, producing 10,000 balls/month) but there are also some very large firms (the highest reported employment and production are 1,700 people and 275,000 balls per month, respectively).[29] Profit rates vary across ball types but are generally low, approximately 8 percent at the median and 12 percent at the 90th percentile.[30] The corresponding firm size and profit margins in the full sample (Panel B) are slightly larger, indicating that the late responders are larger and more profitable 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; firm age is 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 11 years (9 years at the median). One other salient fact is that the vast majority of firms pay pure piece rates to their cutters and printers. Among the initial responders, 79 of 85 firms pay a piece rate to their cutters, with the remainder paying a daily, weekly or monthly salary sometimes accompanied by performance bonuses.[31]

5 Experiment 1: The Technology-Drop Experiment

In this section we briefly describe our first experiment, the technology-drop experiment. For the purposes of the current paper, the first experiment mainly serves to provide evidence of low adoption, a puzzle we investigate using our second experiment, motivated in Section 6 and described in Section 7.

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 on the possible role of credit constraints in the technology-adoption decision.[32] The top panel of Table 5 summarizes

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[29]The employment numbers understate the true size of firms since the most labor intensive stage of production, stitching, is often done outside of firms in stitching centers or homes.

[30]For further discussion of the heterogeneity in profit rates (mark-ups) across firms, see Atkin, Chaudhry, Chaudry, Khandelwal, and Verhoogen (2015).

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

[32]In an experiment with micro-enterprises in Sri Lanka, de Mel, McKenzie, and Woodruff (2008) find very high returns — higher than going interest rates — to drops of cash of US$100 or US$200 (or of capital of roughly similar

the distribution of firms across groups for the initial-responder sample.[33] Because we were initially planning to focus on spillovers, 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. To increase sample size, we also randomized the initial non-responders into three groups using the same proportions as for the initial responders (treating them as a separate stratum). 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 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 not be important.

We began the technology-drop experiment in May 2012. Firms assigned to the technology group were given a four-pentagon offset die, along with a blueprint that could be used to modify the die (combining Figures 10 and 11). They were also given a 30-minute demonstration, which involved first watching the firm's cutter cut a sheet using the traditional die and counting the number of panels, then instructing the cutter how to cut using the offset die and counting the panels.[34] The die we provided cuts pentagons with edge-length of 44 mm. As noted in Section 3, 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 by a local diemaker of their choice. Firms were able to trade in the four-panel offset die we gave them for a two-panel offset die of the same size. 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. 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 offset 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. We find no significant differences across groups.[35] 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 this group responded endogenously to treatment assignment.

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

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magnitudes), suggesting that the micro-enterprises operate under credit constraints. Although our prior was that the US$300 value of the offset die would matter less to the larger firms in our sample, we included the cash-drop component in order to be able to separate the effect of the shock to capital from the effect of knowledge about the technology.

[33]At the moment of assignment, we believed that there were 88 active initial-responder firms with 22 in each stratum. 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.

[34]We continued the demonstration until the cutter was able to cut 272 pentagons from a sheet. In almost all cases, this required one or two sheets; in no case did it require more than three.

[35]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.

of each panel indicate the number of firms that were both active and responded to our surveys. The fourth row shows that a high proportion of tech-drop firms took up our offer of a trade-in for a different die, as mentioned above. 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 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.) The seventh and eighth rows report adoption as of August 2013 using the "conservative" and "liberal" adoption measures discussed in Section 4 above. Using the liberal adoption variable, in the full sample there were five adopters in the tech-drop group and one in the no-drop group. (In the initial-responder sample, the corresponding numbers are four and zero.) This number of adopters 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.

We have investigated several alternative hypotheses for the low take-up, but found little evidence for the most common existing explanations. Lack of awareness of the technology (the assumption underlying "epidemic" models of diffusion, one of two main categories reviewed by Geroski (2000)) cannot be the explanation among tech-drop firms, since 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. 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 eight 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. It would be hard to rationalize this behavior if the offset die were not profitable for this firm.

We have estimated a number of simple linear probability models relating adoption as of August 2013 to measures of scale of production, quality of output produced, managerial ability and employee skill. Scale may be important to allow firms to spread fixed costs over more unit. Quality may matter because the offset die generates greater cost saving for firms using more expensive, high-quality rexine. Manager and worker skill are often thought to be important for technology adoption. Appendix Tables A.1 and A.2 report the results. They can be briefly summarized: we do not find robust correlations between adoption and any of the covariates reflecting scale, quality, manager or employee skill. 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 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 why they had not adopted the new technology, providing nine options (including an "other" category). Table 8 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.)

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, which is an exception to the local norm of piece-rate contracts: 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. The fact that this large early adopter uses an uncommon incentive structure for cutters and printers seemed very suggestive.

We also feel that it is useful to quote at some length from field reports submitted by our own survey team.[36] 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 they are useful to capture the flavor of the owner-cutter interactions that we seek to capture in the theoretical model. As 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 Rs 15,000 (US$150) incentive payment to demonstrate competence in using the offset die.[37] 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 [Rs] 15,000 is not worth all the tensions in future.

It appears in this case that the cutter, anticipating that the owner would not adjust his wage, sought to withhold information about the offset die in order to avoid a future decline in his pay. The cutter declined to participate and the firm was not treated.

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[36]The team included our project manager, Tariq Raza, who wrote the reports, and staff of the RCONS survey firm.

[37]We also offered one printer per firm an incentive payment of Rs 12,000 (US$120), as described below.

In another firm, the owner, who had agreed to participate in the treatment, was skeptical when the enumerators returned to test the cutter. 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."*

It appears that the cutter had been misinforming the owner. But the cutter did not hide the performance of the die in the cutting process itself, likely either because it was difficult to do so or because he did not want to jeopardize his incentive payment.

> *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 offset 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 [Rs] 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.

6.2 A model of organizational barriers to adoption

The survey results and anecdotes point to misaligned incentives within the firm as an explanation for limited technology adoption. If firms pay piece rates and do not modify the payment scheme when adopting, owners enjoy the gains from reduced input costs but cutters — and to a lesser extent printers — bear the costs of increased labor time. Workers therefore have an incentive to misinform the owner about the value of the technology. One interesting question is why owners are

influenced by the misinformation from workers, given that they are presumably aware that workers have such an incentive. A distinct but related question is why owners and workers are not able to arrive at an agreement to share the gains from adoption. We now develop a cheap-talk model in a principal-agent setting that captures the intra-firm dynamics we have observed, addresses the two questions above, and motivates our second experiment. We recognize that other models with misaligned incentives and an ability of cutters to sway the adoption decision may generate similar predictions. But the model in this section has the advantage that it parsimoniously captures what we believe are the main forces at play and is consistent with the qualitative information above and the quantitative results presented below in Sections 7 and 8.

6.2.1 Set-up

Consider a one-period game. There is a principal (she) and an agent (he). The principal can sell any output q at an exogenously given price p. The principal incurs two costs: a constant marginal cost of materials, c, and a wage $w(q)$ that she pays to the agent. Her payoff is $\pi = pq - w(q) - cq$. The agent produces output $q = se$ where s is the speed of the technology (e.g. the cuts per minute), and e is effort, which is not contractible and is costly to the agent to provide. The agent has utility $U = w(q) - \frac{e^2}{2}$ and an outside option of zero.

Technologies are characterized by speed, s, and materials cost, c. There is an existing technology with (s_0, c_0). There is a new technology, which can be one of three types:

- Type θ_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 it as the "bad" technology.

- Type θ_2, with $c_2 < c_0$ and $s_2 < s_0$. This technology lowers material costs but is slower than the existing technology. It is analogous to our offset die.

- Type θ_3, with $c_3 = c_0$ and $s_3 > s_0$. This technology dominates the existing technology because it has the same material costs but is faster.

The principal has prior ρ_i that the technology is type θ_i, with $\sum_1^3 \rho_i = 1$. We assume that the agent knows the type of technology with certainty. While this is clearly an extreme assumption, it captures in an analytically tractable way the observation from our qualitative work that the cutters are better informed about the cutting dies (which they work with all day every day) than are owners. Adopting the new technology requires a fixed cost, F.

We assume that contracts must be of the linear form $w(q) = \alpha + \beta q$, where $\beta \geq 0$.[38] We further assume that the agent has limited liability, $\alpha \geq 0$ — a reasonable assumption given that no worker in our setting pays an owner to work in the factory. Below we will consider cases which differ in the ability of the principal to condition the piece rate, β, on marginal cost, c, a characteristic of the technology that will in general only be revealed ex post.

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[38]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. Also, we rule out by assumption the possibility that the contract can be conditioned on the message sent by the agent, implicitly assuming that the costs of implementing such contracts are prohibitively high.

In Stage 1 of the game, the principal chooses a wage contract. In Stage 2, Nature reveals the technology type to the agent. In Stage 3, the agent can send one of three costless messages, $\{m_1, m_2, m_3\}$, regarding the type of the new technology.[39] In Stage 4, the principal decides whether to adopt the new technology, given the agent's message. In Stage 5, 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 agent sends his signal.[40]

Given this setup, the optimal effort choice for the agent, for a given β, is $e = \beta s_i$ (since $\arg\max_e \left(\alpha + \beta s_i e - \frac{e^2}{2}\right) = \beta s_i$). In all the cases we consider below, the limited-liability constraint binds and the principal will set $\alpha = 0$. Conditional on technology θ_i being used, the agent's utility is then:

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

which makes it clear that conditional on β the agent prefers faster technologies. Given the agent's optimal effort choice, the principal's profit from adopting technology type θ_i can be written as a function of the piece rate β. Writing $\pi(\beta, \theta_i)$ as $\pi_i(\beta)$ to reduce clutter, we have:

$$\pi_i(\beta) \;\;=\;\; s_i^2 \beta \left(p - \beta - c_i\right) - F \cdot \mathbb{1}(i = 1, 2, 3) \tag{2}$$

where β need not be the optimal choice for technology θ_i.

As a preliminary step, it is useful to consider the optimal contract under two benchmark cases. In the first, suppose that the principal is fully informed about the technology. In this case, 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 α. With the limited-liability constraint this is not possible. Since the agent's effort ($e = \beta s_i$, as above) is independent of α, the principal sets $\alpha = 0$. The optimal contract for a known technology type θ_i is then:

$$\alpha_i = 0, \ \beta_i = \frac{p - c_i}{2} \tag{3}$$

Note that the optimal piece rate depends on marginal cost. The optimal piece rate for the material-saving technology (type θ_2) is higher than for the existing technology since $c_2 < c_0$.[41] In this case, the principal would like to incentivize more effort from the agent because profits per cut are higher.

In the second benchmark, suppose that the principal is imperfectly informed but receives no signal from the agent. In this case, it can be shown that the principal, if she were to adopt the technology, would choose the wage contract: $\alpha = 0, \widetilde{\beta} = \sum_{i=1}^{3} \lambda_i \beta_i$, where β_i is as in (3) and $\lambda_i = \frac{\rho_i s_i^2}{\sum_1^3 \rho_i s_i^2}$. The optimal piece rate is thus a weighted average of the optimal piece rates in the

[39] In the proofs in the theory appendix, we allow for a richer set of messages and show that doing so does not affect any of our conclusions. Here we limit to three messages for expositional clarity.

[40] Since Nature does not reveal the technology type to the principal, it is not crucial for the analysis whether Nature's move, which we can think of as the initial technology drop by our survey team, happens before or after the wage contract is set. (That is, the order of Stages 1 and 2 can be reversed.) Thus the model can also accommodate a scenario in which the principal's priors are set when our survey team does the technology drop and the technology type is revealed to the agent.

[41] Since $c_3 = c_1 = c_0$, the optimal piece rate for types θ_1 and θ_3 is the same as for the existing technology.

full-information case. Given this contract, the expected profit from adoption is:

$$\widetilde{\pi}(\widetilde{\beta}) = \left(\sum_{i=1}^{3} \rho_i s_i^2\right)\left(\widetilde{\beta}\right)^2 - F \tag{4}$$

where $\widetilde{\pi}(\cdot)$ is defined as the principal's expected profit from adoption based only on her priors; that is, $\widetilde{\pi}(\cdot) \equiv \rho_1 \pi_1(\cdot) + \rho_2 \pi_2(\cdot) + \rho_3 \pi_3(\cdot)$.

As noted above, the aim of the model is to capture the intra-organizational dynamics we have observed, in particular that workers may misinform owners about the value of the technology, discouraging adoption, and that modifying wage contracts may lead to successful adoption. These features are not present under all possible parameter values. To focus on what we consider to be the interesting case in the model, we impose three parameter restrictions. Using the definitions of $\pi_i(\cdot)$ from (2), of β_i from (3), and of $\widetilde{\pi}(\widetilde{\beta})$ from (4), they are:

$$\pi_2(\beta_0) > \pi_0(\beta_0) \tag{5a}$$

$$\pi_3(\beta_2) > \pi_0(\beta_2) \tag{5b}$$

$$\pi_0(\beta_0) > \widetilde{\pi}(\widetilde{\beta}) \tag{5c}$$

Condition (5a) requires that technology type θ_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 θ_2). This in turn will imply $\pi_2(\beta_2) > \pi_0(\beta_0)$; that is, a fully informed principal would adopt type θ_2. Condition (5b) implies that technology θ_3 dominates the existing technology even at the optimal piece rate for type θ_2. This in turn will imply $\pi_3(\beta_3) > \pi_0(\beta_0)$; that is, a fully informed principal would adopt type θ_3. Condition (5c) implies that a principal with no information beyond her priors would choose not to adopt. Using these conditions, Appendix A.1 provides a number of preliminary results for the profit functions defined in (2) which will be useful below.

6.2.2 No conditional contracts

We first consider the case in which the (imperfectly informed) principal is not able to condition the wage payment on marginal cost, which is only revealed ex post. In this case, there is an equilibrium in which, if the technology is type θ_2, the agent misinforms the principal about it and the principal does not adopt.

Proposition 1. *Under (5a)-(5c), if contracts conditioned on marginal cost are not available, then the following strategies are part of a perfect Bayesian equilibrium.*

1. *In Stage 1, the principal offers wage contract $(\alpha^* = 0, \beta^* = \frac{p-c_0}{2})$.*

2. *In Stage 3, the agent:*

    (a) *signals m_1 if the technology is type θ_1 or θ_2,*

    (b) *signals m_3 if the technology is type θ_3.*

3. In Stage 4, the principal:

   (a) adopts if the agent signals m_2 or m_3,

   (b) does not adopt if the agent signals m_1.

For conciseness, Proposition 1 only states the on-equilibrium-path strategies. Appendix A.2 provides a formal proof that covers the entire strategy space. Intuitively, given that the principal has committed in Stage 1 to a piece rate (not conditioned on cost), the agent strictly prefers the existing technology to type θ_2. So if the technology is type θ_2, the agent signals that it is type θ_1, the bad technology, to discourage adoption, and the principal does not adopt.[42] Why does the principal pay attention to the agent's signal, given that she knows that the agent has the incentive to misinform her in this way? The intuition is that the players' interests are aligned if the technology is of type θ_1 or θ_3, and 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-θ_2 state rather than to ignore the agent's advice altogether.

In proving Proposition 1, we derive two useful additional results. First, we show that under the conditions of Proposition 1 (no conditional contracts, restrictions (5a)-(5c) hold), there does not exist an equilibrium in which the agent always truthfully reveals the technology type. That is, information about the technology is necessarily lost in some states of the world. Intuitively, if the agent were to reveal the technology type truthfully, then the principal would want to adopt type θ_2 and not type θ_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 θ_2 to be type θ_1.

Second, the equilibrium outlined in Proposition 1 is particularly salient in the sense of being the "most informative" among the set of possible equilibria. In our set-up, there exists a cheap-talk subgame for every possible choice of the piece rate, β. We show (in Lemma 5 in Appendix A.2) that in each subgame there are at most two possible types of equilibria, an informative type (in which the agent communicates whether $\theta = \theta_3$ or $\theta \in \{\theta_1, \theta_2\}$) and a babbling type. (If we treat what Crawford and Sobel (1982) call "essentially equivalent" messages — those that induce the same action in a given equilibrium — as identical, then there are at most two equilibria in each subgame, an informative one and a babbling one.) Crawford and Sobel (1982) and others have argued that it is reasonable to expect players to coordinate on the most informative equilibrium in cheap-talk interactions. The Proposition-1 equilibrium is the most informative in two respects. One, players coordinate on the informative equilibrium in the subgame on the equilibrium path. Two, the equilibrium is robust to the restriction that players coordinate on the informative equilibrium in all subgames off the equilibrium path as well. Indeed, under this restriction (and modulo treating "essentially equivalent" messages as identical), the equilibrium described in Proposition 1 is unique.

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[42]In the language of Aghion and Tirole (1997), the principal in this equilibrium retains formal authority over the adoption decision but effectively cedes real authority to the agent.

6.2.3 Conditional contracts

Now suppose that in Stage 0 the principal can pay a transaction cost G and gain access to a larger set of wage contracts — in particular to contracts that condition the piece rate on marginal cost, c. This larger set of possible contracts includes contracts that offer a per-sheet incentive to reduce waste of laminated rexine, as these can be interpreted as an increase in the piece rate conditional on using the lower-marginal-cost technology.[43]

The optimal contracts under the existing technology and types θ_1 and θ_3 are identical (since $c_3 = c_1 = c_0$ and hence $\beta_3 = \beta_1 = \beta_0$, where the β_i are defined by (3)). The ability to condition on marginal cost matters only if the technology is type θ_2. Allowing for conditioning, the principal can offer contracts of the form:

$$w(q) = \alpha + (\beta + \gamma)q \qquad \text{if } c = c_2 \tag{6}$$

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

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

Proposition 2. *Under (5a)-(5c), if contracts conditioned on marginal cost are available at fixed cost G, then the following strategies are part of a perfect Bayesian equilibrium.*

1. *In Stages 0 and 1,*

   (a) *if*
   $$G < \rho_2 \left[\pi_2(\beta_2) - \pi_0(\beta_0) \right], \tag{7}$$
   then the principal pays G and offers wage contract $\left(\alpha^{**} = 0, \beta^{**} = \frac{p-c_0}{2}, \gamma^{**} = \frac{c_0-c_2}{2} \right)$.

   (b) *if $G \geq \rho_2 \left[\pi_2(\beta_2) - \pi_0(\beta_0) \right]$, then the principal does not pay G and offers wage contract $\left(\alpha^{**} = 0, \beta^{**} = \frac{p-c_0}{2} \right)$.*

2. *In Stage 3,*

   (a) *given $\left(\alpha^{**} = 0, \beta^{**} = \frac{p-c_0}{2}, \gamma^{**} = \frac{c_0-c_2}{2} \right)$, the agent signals truthfully.*

   (b) *given $\left(\alpha^{**} = 0, \beta^{**} = \frac{p-c_0}{2} \right)$, the agent:*

       i. *signals m_1 if the technology is type θ_1 or θ_2,*

       ii. *signals m_3 if the technology is type θ_3.*

3. *In Stage 4, the principal:*

   (a) *adopts if the agent signals m_2 or m_3,*

   (b) *does not adopt if the agent signals m_1.*

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[43]In our framework, the only way to reduce waste is to use the low-marginal-cost technology; exerting additional effort would raise output but not reduce waste per sheet.

Again, for conciseness, the proposition only states the on-equilibrium-path strategies. Appendix A.3 provides a proof covering the entire strategy space. Intuitively, if the principal offers the conditional contract, the higher piece rate if $c = c_2$ is enough to induce the agent to prefer adoption if the technology is of type θ_2.[44] Paying the transaction cost, G, will be in the interest of the principal if (7) is satisfied, which is to say that the expected additional profit from adopting type θ_2 (with the optimal piece rate for type θ_2) is greater than the fixed cost of offering the new contract. In this case, the availability of the conditional contract solves the misinformation problem, in that type θ_2 will be adopted in equilibrium. At the same time, if (7) is not satisfied, for instance because the principal has a low prior, ρ_2, then there again exists the equilibrium of Proposition 1, in which type θ_2 is not adopted.

6.2.4 Discussion

Our model suggests two possible reasons why owners would not modify contracts to solve the misinformation problem. One is simply that the principal is unaware of the existence of the conditional contract; this corresponds to the no-conditional-contracts case. The conditional contract may be an organizational innovation that was previously unknown, at least to some firms, in the same way that our technical innovation was previously unknown.

Another reason, corresponding to the conditional-contracts case, is that the principal is aware of the conditional contract, but perceives the cost of implementing the conditional contract to be higher than the expected benefit. The transaction cost, G, can be interpreted in a number of ways. It may be that social norms have arisen around standard piece-rate contracts, such that firms incur a cost in terms of reduced worker morale if they deviate from the contract perceived to be normal or fair. Alternatively, firms may worry that by paying higher piece rates if the technology is type θ_2, workers will also demand higher piece rates under other scenarios, which will be costly in the long run. It 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 type θ_2.[45] Finally, the fixed cost can be interpreted in light of the well-known ratchet effect (e.g. Gibbons (1987)). If a worker paid a piece rate discovers a labor-saving innovation, he may not bring these to the attention of the owner if he expects the principal to cut the piece rate in response.[46] It may be optimal for the principal to commit to not changing the piece rate in order to encourage labor-saving innovations. If most innovations in Sialkot are labor-saving, this may explain why piece rates are sticky and why it may be costly for firms to start offering conditional contracts — 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 6), which was a labor-saving innovation. It seems plausible that firms in Sialkot expect new cutting technologies to be labor- rather than material-saving and

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[44]Note that, using the notation of (3), $\beta^{**} = \beta_0$ and $\beta^{**} + \gamma^{**} = \beta_2$, the optimal piece rate for type θ_2 in the full-information case.

[45]In our simple model, such commitment would not be needed since the firm would want to pay the higher piece rate ex post, but such a commitment device might be needed in more complicated models.

[46]In our framework, this can occur if the agent's outside option is non-zero and his participation constraint binds.

that they are reluctant to modify piece rates for this reason.

These two possible explanations for the stickiness of labor contracts — that owners are not aware of the existence of conditional contracts, and that they do not perceive the benefits of such contracts to outweigh the costs of adopting them — have similar implications for the players' behavior. The misinformation equilibrium exists in both circumstances. The key point is that, for whatever reason, many owners did not in fact adjust labor contracts. This in turn left scope for our incentive intervention, described below, to have an effect.

6.2.5 Motivation for incentive intervention

Testing our theory presents a number of practical challenges. In principle, one approach would be to pay the transaction cost, G, for firms and examine whether they change the labor contract and adopt the technology as predicted. But the transaction cost is not observable and depends on various dimensions of complex social dynamics within firms; it is not clear how much we (the experimenters) would pay, or to whom. Another approach would be to offer the new, conditional piece rate (or the additional payment per piece corresponding to γ) ourselves. The practical issue here is that the firms are reluctant to share the detailed production information that would be required to implement such a piece-rate payment. The challenges we faced in collecting information from firms in the earlier survey rounds indicated to us that it would be impossible to manipulate the piece rate directly in our second experiment.[47]

Facing these constraints, we opted for a third approach: we offered a one-time lump-sum payment to one cutter and one printer per firm, conditional on revealing the offset die to be cost-saving in front of the owner. In Appendix A.4, we prove a formal proposition that if such a conditional lump-sum payment by a third-party experimenter is sufficiently large, then there exists an equilibrium in which the agent reveals truthfully and the principal adopts, even if the principal would not have offered the conditional contract on her own. Intuitively, the incentive payment plays the same role as the conditional piece rate γ^{**} in Proposition 2: it raises the payoff to the agent of signaling truthfully when the technology is of type θ_2. Empirically, the main implication is that we would expect the incentive intervention to increase adoption of the offset die.[48] It is worth noting that "sufficiently large" in this context is relative to the possible wage losses of a single cutter, not to the revenues or profits of a firm. Indeed, we will see below that a lump-sum incentive payment that appears small from the point of view of firms has a large effect on adoption.

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[47]In the end, one-third of firms chose not to participate in the much less invasive intervention we decided to implement; see Section 7 below for details. This confirmed our earlier belief that firms' willingness to participate would be limited.

[48]The equilibrium with truthful revelation and adoption is not unique — as discussed above, there are always equilibria with babbling — but we would expect some players to arrive at it, especially in the view advanced by Crawford and Sobel (1982) and others that it is reasonable to expect players to coordinate on the most informative equilibrium.

7 Experiment 2: The Incentive-Payment Experiment

7.1 Experimental design

Motivated by our theoretical hypotheses, we conducted the incentive-payment experiment in September-November 2013. To avoid interfering with the process of diffusion to the non-tech-drop firms, we focused on only the 35 tech-drop firms (including both initial responders and initial non-responders). The 31 still-active among these were divided into four similarly sized strata:[49] (1) firms in the two smaller strata from the tech-drop experiment that had not yet 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.[50] Within each stratum, firms were randomly assigned with equal proportion to a treatment subgroup (which we call Group A) and a control subgroup (Group B). There were 15 firms in Group A and 16 in Group B.

To firms in Group B we gave a reminder about the offset die and the new cutting pattern, and explicitly informed them about the two-pentagon variant of the offset die (which, as noted above, had proven more popular than the four-pentagon offset die we originally distributed.) We also offered to do a new demonstration with their cutters. To each firm in Group A, we gave the same refresher, the same information about the two-pentagon variant, and the same offer of a new demonstration. In addition, we explained the misalignment of incentives to the owner and 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 they demonstrate competence in using the new technology in front of the owner. If the owner agreed to the intervention, we explained the intervention to one cutter and one printer chosen by the owner, paid them 1/3 of the incentive payment on the spot, and scheduled a time to return to test their performance using the die.[51]

The performance target for cutters was 272 pentagons from a single sheet in three minutes using the offset die. The target for the printer was 48 pairs of offset pentagons in three minutes.[52] We provided the owner with 20 laminated rexine sheets and printing screens for offset pentagon pairs for his workers to practice with, and a nominal Rs 5,000 (US$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

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[49]At the time of randomization, we believed that 34 of these firms were still active. Three of these 34 firms were subsequently revealed to have stopped manufacturing soccer balls.

[50]As shown in Table 7, there were three adopters as of August 2013 in the initial-responder sample using the conservative definition (which is based on our survey data), and four adopters according to the liberal definition (which combines survey data with field reports submitted by our enumerators). We stratified using the liberal definition, our preferred measure.

[51]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 that he pass on the money to the employees, and we acceded to this request.

[52]The 3-minute targets were chosen after conducting speed tests at two of the pilot firms mentioned in Section 5. They are approximately 33 percent 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.

so, we allowed for a buffer of 30 seconds and 5 pentagons for cutters and 30 seconds for printers.[53]

Table 9 evaluates baseline balance by comparing firm characteristics across Group A and Group B firms at the time of our visit to explain the intervention (September 2013). No differences in means are statistically significant. It appears that randomization was successful.[54]

7.2 Results

Ten of the 15 Group A firms agreed to participate in the experiment.[55] Table 10 reports the times achieved by the chosen cutter at each firm (all using the two-pentagon variant of the offset die). The average time was 2 minutes and 52 seconds, approximately 27 percent longer than the typical time to cut with the traditional die (2 minutes and 15 seconds). For this reason, we believe that the 50 percent increase in labor time factored into the cost calculations 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 offset die does not increase labor time for printing.

To measure short-run adoption responses, we carried out a survey round in January-March 2014 (Round 6 of our survey), 2-5 months after the completion of the incentive-payment intervention. Before turning to the formal regressions, it is useful to examine the raw adoption statistics. Of the 10 Group A firms that agreed to participate in the experiment, two had already adopted the die. Of the remaining eight firms, five subsequently adopted using the liberal definition (or four using the conservative definition). Of the 16 Group B firms, three firms had already adopted prior to the invention. None of the remaining 13 firms adopted in the short run, by either measure. To examine medium-run responses, we carried out another survey round in October-December 2014 (Round 7 of our survey), 11-13 months after the completion of the intervention. If the technology is beneficial as we have argued, one would expect it eventually to be adopted by all firms (once there has been sufficient social learning, for instance) and there would then be no long-run effect of our incentive treatment. In this sense, it would be reasonable to expect the medium- and long-run treatment effect to be smaller than the short-run one. Indeed, by Oct.-Dec. 2014, one initial non-adopter in Group B (i.e., a Group B firm that had not yet adopted at the start of Experiment 2) had adopted the die (by either definition).

Table 11 uses the liberal adoption measure to assess formally the impact of the incentive-payment intervention on adoption rates. All regressions include dummies for the four strata described above. Panel A reports impacts on adoption in the short run, and Panel B in the medium run. Focusing on the short run first, the first-stage estimates (Column 1) indicate, not surprisingly, that assignment to Group A is significantly associated with greater probability of receiving

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[53]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.

[54]Because of an error by our enumerators, one firm that was assigned to 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. As neither firm adopted, our results hold with the original randomization (available upon request).

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

the incentive-payment treatment; that is, we have a strong first stage. The dependent variable in Columns 2-4 is a 0/1 indicator for whether a firm has adopted. The OLS estimate in Column 2 — from a regression of adoption on treatment — is positive and significant, but one might be worried about selection into treatment. The reduced-form (intent-to-treat) result in Column 3 — from a regression of adoption on assignment to Group A — does not suffer from such selection issues and indicates a positive and significant (at the 5 percent level) causal relationship between assignment and adoption. The estimate indicates that the probability of adoption increased by 0.32 among those assigned to treatment. The IV estimate (the effect of treatment on the treated) is substantially higher: 0.48. 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. The medium-run ITT estimate in Panel B is slightly lower at 0.27 (and statistically significant at the 10 percent level) because of the one Group B firm that adopted in the second six-month period after the intervention.[56] Table 12 reports very similar results using the conservative adoption measure — the short-run ITT is 0.31 and statistically significant at the 5 percent level, and the medium-run ITT is 0.26 and statistically significant at the 10 percent level.

To check robustness, Table 13 reports results using an alternative indicator of adoption: 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 yet produced with it at the time of our Oct.-Dec. 2014 survey round.)[57] Table 13 shows that the positive causal effect of the incentive-payment treatment on adoption is robust to using this alternative measure. As before, we report both short- and medium-run impacts. The short- and medium-run ITT estimates are 0.27 and 0.28, respectively, and are both statistically significant at the 5 percent level.

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 25,872,000 possible treatment assignments that would produce coefficients as large as or larger than the ones we find (holding the observed outcome for each firm unchanged).[58] This procedure does not require asymptotic approximations. Given the selection discussion above, we focus on the more conservative ITT estimates in Column 3 of Tables 11-13. Figure 15 plots the distribution of coefficients obtained from regressing the liberal adoption measure on assignment to Group A for the millions of possible treatment assignments. Because of the small number of adopters, there are only a handful of possible coefficients, despite the large

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[56]The number of observations falls by two in the medium-run results because there were two firms that exited.

[57]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 17), purchased its first die (beyond the four-panel offset die we originally gave) following the beginning of our intervention.

[58]Within each of the four strata, we assigned treatment status with equal proportion. The stratum of smaller firms contained 6 firms, the stratum of larger firms contained 12 firms, the stratum of initial non-responders contained 8 firms and the stratum of already-adopters contained 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.

number of possible assignments. The dashed grey vertical lines represent the critical values associated with two-sided hypothesis tests that the coefficient we find is different from zero at significance levels of 10, 5 and 1 percent, respectively. (Some of these lie on top of one another; see the notes to the figure.) The solid red vertical line denotes the actual ITT effect we found in Column 3 of Table 11. For the short run (left panel), our estimated ITT is the most extreme coefficient that could be observed under any treatment assignment and is equal to the critical value for a 1 percent significance test. For the medium run (right panel), where we would expect the treatment effect to have begun to attenuate, a fraction 0.061 of assignments are more extreme and our point estimate is equal to the critical value for a 10 percent significance test. Figure 16 reports the corresponding plots using the conservative adoption measure. Our short-run ITT estimate lies between the 1 and 5 percent critical values, with a fraction 0.018 of assignments being more extreme. Our medium-run ITT estimate lies just below the 10 percent critical value with a fraction 0.118 of assignments being more extreme. Figure 17 presents a similar analysis for our alternative indicator of adoption, die purchases. The short-run ITT estimate is the most extreme outcome possible and is equal to the 1 percent critical value. The medium-run ITT estimate is equal to the 5 percent critical value, with a fraction 0.036 of assignments being more extreme.

To sum up: although the level of significance dips slightly below 90 percent using the more conservative adoption measure and the small-sample-robust permutation test in the medium-run specification, when we would expect the effect to have begun to attenuate, overall the results strongly suggest that, consistent with our theoretical model of misaligned incentives, the incentive-payment treatment spurred adoption among firms.

8   Additional Evidence on Mechanisms

In this section, we present additional (non-experimental) evidence on two key features of our theoretical model: wage stickiness and information flows within the firm. So as not to reveal the existence of the offset die to non-tech-drop firms, most of the questions we discuss were asked only of the 31 tech-drop firms involved in the second experiment, and we focus on these tech-drop firms throughout this section.[59]

To shed light on wage stickiness, we recorded the wages of cutters and printers for each month between August 2013 and September 2014. Generally, it appears that firms change wages relatively seldom. Of the 24 tech-drop firms that provided complete information, 10 did not change the head cutter's wages at all over the entire 13 month period, a period of 8.4 percent annual inflation (Appendix Table A.3). Thirteen out of 24 did not change the wage for the head printer. This evidence is corroborated by the survey responses from the head cutters and printers themselves: only 3 out of 17 cutters who responded indicated that their wage had changed during this period, and only 4 out of 17 printers reported a change. We asked firms why they changed wages, and the responses for the few firms that provided answers are in Appendix Table A.4. The two main reasons cited by owners were (a) inflation and (b) the change was a regular "end of year" change. Only one firm reported

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[59]This section examines responses from Round 7 of our survey, conducted in Oct.-Dec. 2014.

changing wages because of the offset die. In addition to the reasons discussed in Section 6.2.4 above, another possible reason for the wage stickiness is that it is conventional to use round numbers for piece rates. Appendix Figure A.2 shows that 78 percent of piece rates are 1, 1.5, 2, 2.5, 3 or 4 Rupees per ball. Given this convention, it may be that wage increases must be reasonably large when they occur. These several pieces of evidence reinforce the idea that piece rates are sticky, consistent with the ideas (a) that they are chosen in Stage 1 of the game, prior to the technology arriving, and (b) that there is a significant cost to adopting contracts that involve changing piece rates.

We also asked owners and head cutters directly why payments were not conditioned on the technology and whether such a possibility was ever discussed. The reason cited most often by owners (6 out of 18) is that offering such incentives would lead workers to expect additional incentives in the future. The next two most common answers were that workers would perceive these incentives as unfair or that the owners did not think of it (Appendix Table A.5). Cutters overwhelmingly state that they feel it is not their place to make suggestions to the owner about the payment schemes (Appendix Table A.6). In almost no case did the owner report discussing payments to adopt the die with any employee (Appendix Table A.7). Similarly, cutters never report talking to the owner or other co-workers about payments to adopt the die. The responses are consistent with the hypothesis that owners and cutters were largely unaware of the possibility of conditional contracts, but also with the hypothesis that both were aware of the contracts but that there were transaction costs associated with adopting them.

Turning to information flows within the firm, we asked owners if they had had a conversation with their head cutter, other cutters or head printer about whether to adopt the offset die.[60] It appears that this question did not capture all forms of communication between owners and cutters. For instance, of the 10 firms that reported "cutters unwilling" as the main reason for not adopting the technology in Round 4 of our survey (Table 8), only six reported that they had had a conversation with the head cutter about whether to adopt the die.[61] Presumably the remainder received signals from cutters through less direct means, or were too proud to admit to taking advice from subordinates. With this caveat, the responses do suggest that owners are being swayed by the opinions of cutters in their adoption decisions. Ten of 22 respondents reported consulting with their head cutter about the decision (Appendix Table A.8). There is a clear association between what the cutter recommends and what owners eventually do. Appendix Table A.9 reports the recommendations given by the cutters in the 10 cases where owners report consulting them, and the firms' corresponding adoption decisions using the liberal definition. In all three instances where the head cutter recommended adopting, the firm adopted; in four of the six instances where the head cutter's recommendation was negative, the firm did not adopt.[62] These responses are consistent with the assumption in the model that owners are less informed than cutters, and the result that

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[60]The exact wording of the questions were "Did you have a conversation with [the following employee] about whether you should adopt the offset die?" and "If yes, what did they say?" with response codes "(a) the technology is beneficial and should be adopted, (b) the technology is not beneficial and should not be adopted, (c) not sure whether the technology is beneficial or not, (d) other (_____)."

[61]In all six cases, the cutters recommended against adoption.

[62]Using the conservative definition, in five of the six cases the firm did not adopt.

in some circumstances the principal finds it worthwhile to follow the cutter's advice.

Additional corroborative evidence for our story comes from firms' experience with a previous innovation in the cutting process. Prior to 1994, all firms used a single-panel die to cut pentagons. In 1994, the first firms began using the two-panel pentagon die pictured on the right-hand side of Figure 6, referred to in Sialkot as the "back-to-back" die. This die is much faster, since each strike by the hydraulic press cuts two pentagons, and does not appear to have reduced the number of pentagons cutters were cutting per sheet. Owners report that the back-to-back die was adopted much more quickly than our offset die has been, and with little resistance from cutters. All 14 owners who could recall the speed of adoption indicated that they adopted the die within six months of hearing about it (Appendix Table A.10). Furthermore, 23 out of the 24 respondents report there was no resistance among cutters to adopt this die (Appendix Table A.11) and very few firms changed their payment structure in any way (Appendix Table A.12). Relating this evidence to our theory, the back-to-back die can be interpreted as corresponding to technology type θ_3 (equal marginal cost but faster than the existing technology). The fact that the back-to-back die was adopted quickly and with little resistance from cutters — consistent with what our model would predict for a type-θ_3 technology — reinforces the idea that the misalignment of incentives for our offset die is responsible for the slow adoption of it.

9   Alternative Hypotheses

In this section, we examine what we consider to be the two leading competing explanations for the results of our second experiment: (1) that we mechanically induced firms to adopt by subsidizing the fixed costs of adoption, rather than by aligning incentives and inducing information flows within firms; and (2) that the second experiment increased the salience of the new technology and this in itself led firms to adopt.

9.1   Subsidies for fixed costs

Suppose in our model that the principal and agent had the same information about the technology. The owner would then simply weigh the expected variable cost reduction from the new technology against the fixed costs of adoption, F. These fixed costs might include a lump-sum bonus to workers to compensate them for a learning period in which their incomes are reduced. Our incentive-payment experiment could be seen as providing a subsidy for these fixed costs, and the subsidy may itself have induced the owner to adopt.

Is this a quantitatively plausible explanation of our findings? To organize our thinking about this question, we can write the present discounted value of expected additional profit from adoption for firm f as follows:

$$\Pi_f = -F_f + P \sum_{t=1}^{\infty} \frac{NVB_f}{(1+r)^t} = -F_f + P \left(\frac{NVB_f}{r} \right) \tag{8}$$

where F_f are fixed costs of adoption, which must be paid up front and may be firm-specific; P is

the probability perceived by the firm that the technology works as we said it does; NVB_f are net variable benefits per cutter per month; and r is the market interest rate.[63] Net Variable Benefits can be calculated for each firm following the method of Section 3.3; we assume that these are constant over time. For firms that did not have to buy the die (i.e. the tech-drop firms) a conservative estimate of "observed" fixed costs (i.e. expenditures on items that we have been able to see) is Rs 10,800/US\$108.[64] In this section, we make the assumption that the Rs 32,000/US\$320 we paid in the incentive-payment treatment were also necessary and part of the true fixed cost of adoption.[65] We thus take the total observed fixed costs to be Rs 42,800/US\$428.[66] Including the incentive payments in fixed costs seems conservative; in the incentive-payment experiment, only one worker felt that the payment was insufficient to cover his costs of adoption, suggesting that the incentive payments were greater than the "training" cost faced by workers in the great majority of firms.

As a first step toward answering the quantitative plausibility question, suppose that there is no uncertainty about the technology (i.e. $P = 1$) and no unobserved fixed costs beyond the US\$428 mentioned above. Under these assumptions, (8) can be reconciled with non-adoption only if firms face extremely high interest rates and hence have a small effective discount factor $1/(1+r)$.[67] The values of firm-specific interest rates that set $\Pi_f = 0$ in (8) represent lower bounds on the firm-specific interest rates for non-adopters. At the 10th percentile, the lower bound is 13.6 percent per *month*; at the 90th percentile, the lower bound is 134 percent per *month*. We asked firms explicitly about the interest rates they face, and the responses ranged from 9 percent to 25 percent per *year*; these are an order of magnitude lower than the implied lower bound for most firms. That is, in the absence of both uncertainty about the technology and unobserved fixed costs, the interest rates (or rate of discounting) that would be required to explain the low initial rates of adoption appear to be implausibly high.

This argument leaves open the possibility that some combination of uncertainty and unobserved fixed costs can account for the low initial rates of adoption we observed. To address this possibility, we take a different approach: we allow for both uncertainty and unobserved fixed costs and ask whether these can explain both the low rates of initial adoption *and* the magnitude of the response to our incentive-payment intervention. The unobserved fixed costs may represent attention costs

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[63]Here we are abstracting from the possibility that firms can learn from others about the profitability of adoption, which would tend to lead them to delay adoption (and wait for others to adopt), as emphasized by Foster and Rosenzweig (1995). Such an effect could help to explain low initial adoption, but not the large increase in adoption in response to our second experiment, and the argument of this section that our subsidies were too small to generate the latter would continue to hold in a more complex social-learning model.

[64]As discussed in Section 3.3, the fixed costs are Rs 800/US\$8 to have screens redesigned and remade and Rs 10,000/US\$100 for an offset die for the combing machine.

[65]As discussed in Section 7.1, we paid Rs 15,000/US\$150 to the cutter, Rs 12,000/US\$120 to the printer, plus Rs 5,000/US\$50 to the owner to cover overhead. In Section 3.3 we assumed that workers wages went up by 50 percent to compensate them for using the slower technology. The discussions in Sections 6 and 8 suggest that many firms do not adjust their wages and so in this section we remove this component and instead assume that the firm must only pay the one-off conditional wage payment.

[66]We take these to be the fixed costs *per cutter*. This is a conservative assumption since it is possible that firms could, for example, share the combing machine across cutters.

[67]This is another way of stating the argument from Section 3.3 that the observable fixed costs of adoption can be recouped within a relatively short amount of time by almost all firms.

for the owner or psychic costs involved in changing established routines. We assume, conservatively, that the interest rate is the highest of the self-reported interest rates, 25 percent per year. As a benchmark, we assume that owners place a 50 percent probability on the event that the technology works as we described (i.e. $P = 0.5$); we consider alternative priors below. Under these assumptions, we can place bounds on the values of unobserved fixed costs that can explain the behavior we observe. In particular, simplifying (8), if a firm does not adopt initially, it must be that $\Pi_f < 0$ and hence that $F_f > (0.5)\frac{NVB_f}{0.0187}$. (A 1.87 percent monthly interest rates corresponds to a 25 percent annualized rate.) If a firm adopts in response to the incentive-payment experiment, it must be that $\Pi_f > 0$ after the US\$320 reduction in fixed costs, and hence that $F_f < (0.5)\frac{NVB_f}{0.0187} + 320$. These bounds on fixed costs are plotted by rank in Figure 18 for the 31 firms in the incentive-payment experiment (using the liberal adoption measure). The solid black bars indicate upper bounds on fixed costs for the initial adopters (for which we can only calculate upper bounds). The white bars indicate lower bounds for the never-adopters (for which we can only calculate lower bounds). The solid grey bars indicate lower bounds for initial non-adopters that adopted in response to the incentive treatment (i.e complier in Experiment 2); the black outlines above the solid grey bars indicate upper bounds for these firms. The key point to notice is that the US\$320 subsidy (indicated by the distance between the top of the solid grey bars and the black outlines just above them) is small relative to the implied lower bound on fixed costs for almost all initial non-adopters.

In this context, the key question is whether a plausible distribution of unobserved fixed costs is consistent with the adoption responses and implied bounds illustrated in the figure. It turns out that if we impose even minimal structure on the distribution of unobserved fixed costs then it is very unlikely that the distribution would generate both the initial lack of adoption (which requires that unobserved fixed costs be large) and the large response to the second experiment (which requires that US\$320 make a significant difference to the adoption decisions of a large number of firms). Suppose that fixed costs are distributed log normally:

$$\ln(F_f) = \mu + \varepsilon_f \tag{9}$$

where $\varepsilon_f \sim \mathcal{N}(0, \sigma_\varepsilon^2)$. Using maximum likelihood, we can estimate the values of μ and the error variance, σ_ε^2, that can best account for the observed adoption responses in both experiments.[68]

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[68]We use the short-run liberal adoption rates for this exercise. Let $adopt_{1f}$ denote an indicator if firm f had adopted the technology in Experiment 1, and $adopt_{2f}$ an analogous indicator for adoption after Experiment 2. The log likelihood function for Group A firms is:

$$
\begin{aligned}
L(\mu, \sigma_\varepsilon) \; = \; & \sum_f \left\{ (1 - adopt_{1f})(adopt_{2f}) \ln \left[\Phi \left(\frac{\ln\left[P\left(\frac{NVB_f}{0.0187}\right) + 320 \right] - \mu}{\sigma_\varepsilon} \right) - \Phi \left(\frac{\ln\left[P\left(\frac{NVB_f}{0.0187}\right) \right] - \mu}{\sigma_\varepsilon} \right) \right] \right. \\
& + (1 - adopt_{1f})(1 - adopt_{2f}) \ln \left[1 - \Phi \left(\frac{\ln\left[P\left(\frac{NVB_f}{0.0187}\right) + 320 \right] - \mu}{\sigma_\varepsilon} \right) \right] \\
& \left. + (adopt_{1f}) \ln \left[\Phi \left(\frac{\ln\left[P\left(\frac{NVB_f}{0.0187}\right) \right] - \mu}{\sigma_\varepsilon} \right) \right] \right\}
\end{aligned}
\tag{10}
$$

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Panel A of Table 14 reports these estimates $\hat{\mu}$ and $\hat{\sigma}_{\varepsilon}^2$ under six priors ranging from $P = 0.01$ to $P = 1$. With these estimates in hand, we can ask: what is the ITT estimate we would obtain from a US\$320 subsidy on adoption, the size of the payment in Experiment 2? To answer this question we use $\hat{\mu}$ and $\hat{\sigma}_{\varepsilon}^2$ to simulate fixed cost draws 1,000 times, with Appendix Figure A.3 displaying the full distribution of Group A firms switching from non-adoption to adoption as a result of a US\$320 payment. In Panel B of Table 14, we report the average ITT estimate and the standard deviation from these simulations. The ITT estimates range between 0.01 and 0.10 for priors between $P = 1$ and $P = 0.05$, much lower than the 0.32 (see Panel A of Table 11, Column 3) we obtained in our incentive-payment experiment.[69] Even for the most pessimistic prior of $P = 0.01$, we only obtain an ITT of 0.24. Although such a low prior is theoretically possible, it seems unrealistically pessimistic given the nature of the technology. In summary, it appears that if unobserved fixed costs are the reason for low adoption in Experiment 1, a US\$320 subsidy alone cannot plausibly explain the magnitude of the increase in adoption we observed in Experiment 2.

9.2 Salience

A second alternative explanation is that the incentive-payment treatment increased the salience of the new technology and that this itself led firms to adopt, independent of any effects on information flows within the firm. There are two variants of this explanation. One variant is that the reminder about the technology during the incentive-intervention visit itself "nudged" firms into adoption. This variant can be easily rebutted. We gave the same reminder to the control firms for the incentive intervention (Group B firms) and we saw no firms adopt in the next six months as a result. Also, it is worth noting that we visited all of the tech-drop firms multiple times in our survey rounds. During each of these visits, we discussed the new technology with them and if they were not using it we asked why.

A subtler variant of the salience story is that by putting more money on the table we sent a stronger signal about our own beliefs about the efficacy of our technology, and that this in turn led firms to update their priors about the technology, inducing some firms to adopt. While this explanation is sufficiently flexible that it is difficult to dismiss definitively, it also seems unlikely. We believe that it was clear to firms from the outset, in the initial technology-drop implementation, that we thought that the technology was effective. We then returned to each firm numerous times and in the case of the tech-drop firms discussed the offset die each time. The amount of money we spent on surveying each firm far exceeded the US\$320 payment in the incentive intervention. In short, while in retrospect it seems clear that many owners did not believe us when we told them that the technol-

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The first expression on the right-hand-side of (10) captures the contribution to the likelihood of initial non-adopter Group-A firms who are induced to switch from non-adoption to adoption because of the \$320 subsidy. The second expression captures initial non-adopter Group-A firms who are not induced to switch adoption status. The third expression is the contribution of initial adopter firms. For Group-B firms, the likelihood function is the same except $adopt_{2f} = 0 \; \forall f$ and there is no US\$320 payment inside the argument of the normal CDF, $\Phi(.)$. We pool both groups when maximizing the likelihood function.

[69]Panel C of Table 14 reports the corresponding probabilities that five or more Group A firms adopt in the short-run (recall that the incentive-payment treatment induced five adopters according to the liberal adoption measure). The probability of observing an increase in adoption of that magnitude is exceedingly low, between 0.000 and 0.011 , for all but the most pessimistic prior of $P = 0.01$.

ogy works, it does not appear that their skepticism was based on their beliefs about how strongly we held our beliefs, or that the US\$320 affected their beliefs about how strongly we held our beliefs. It seems more likely that they simply thought all along that we had insufficient knowledge and experience in the industry, and hence that our (strongly held) confidence in the technology was misplaced.

10   Conclusion

This paper has two basic empirical findings. First, despite the evident 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 that has found diffusion to be slow for many technologies, but given the characteristics of our technology — low fixed costs, minimal required changes to other aspects of the production process, easily measured cost advantages of the technology — the low adoption rate seems particularly puzzling. Second, with a modest change to the incentives of key employees in the firm — very small in monetary terms relative to firms' revenues and the benefits of adoption — we induced a statistically significant increase in adoption. This is consistent with the hypothesis that a misalignment of incentives within the firm is an important barrier to adoption. Although we do not observe all of 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 reveal the benefits of the technology to owners.

A natural question is why many owners did not simply change the payment scheme on their own, to give employees a greater incentive to adopt the new technology. Survey evidence indicates that a subset of firms are not aware of the availability of alternative payment schemes, and that a large fraction of firms believe that there are non-trivial transaction costs involved in changing contracts, even implicit ones. One would expect owners to weigh any costs of modifying contracts against the expected benefits of adopting new technologies. If owners have low priors that a beneficial new technology will arrive (or that a technology that has arrived is beneficial), they may rationally be unwilling to pay even quite small transaction costs. Although it is difficult for us to distinguish empirically between lack of awareness of alternative contracts and stickiness of contracts as explanations for why owners did not change payment schemes, the key point for our study is that many owners did not in fact change schemes and this left scope for our very modest incentive intervention to have a large effect on adoption.

Although our empirical results are specific to the setting we study, our findings suggest three implications that we believe are likely to apply more broadly. First, we have provided reasonably direct evidence evidence of a complementarity, in the sense of Milgrom and Roberts (1990, 1995), between a technological innovation (the offset die) and an organizational innovation (conditional wage contracts). We suspect that similar complementarities between technical and organizational innovations exist in many other settings, and that it is common for technology adoption to require organizational changes in order to be successful.

Second, there appears to be a form of inertia in employment relationships that can hinder technological change. We have argued that firms' choices of labor contracts depend on the rate at which beneficial new technologies are expected to arrive. It also appears that labor contracts, once established, are difficult to modify. The implication is that firms and industries that evolve in technologically stable environments may be less able to adapt to technological change than new firms and industries, or firms and industries that evolve in technologically dynamic environments. Simple piece-rate contracts may well have been optimal for firms in Sialkot before we showed up, but the very fact that firms in Sialkot have been producing for decades using them may itself have contributed to low adoption rates of the offset die.[70]

Finally, it seems likely that in order for technology adoption to be successful employees need to have an expectation that they will share in the gains from adoption. Such an expectation may be generated by a variety of different types of contracts, implicit or explicit. But to the extent that firms must rely on the knowledge of shopfloor workers about the value of new technologies or how best to implement them, it appears to be important that some sort of credible gain-sharing mechanism be in place.

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[70]We are not the first to note that many organizations are characterized by a resistance to change; see for instance the literature in organizational sociology following Hannan and Freeman (1984). Beyond documenting such inertia rigorously, one contribution of this paper is to show specifically that labor contracts are a source of inertia in our setting, and that such inertia can be overcome with well-targeted adjustments to incentives.

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Figure 1: "Buckyball" Design

Notes: Figure shows the standard "buckyball" design, based on a geodesic dome designed by R. Buckminster Fuller. It combines 20 hexagons and 12 pentagons.

Figure 2: Making the Laminated Rexine Sheet (Step 1)

Notes: Figure displays workers gluing layers of cloth (cotton and/or polyester) to artificial leather called rexine using a latex-based adhesive to form what is called a laminated rexine sheet.

Figure 3: Cutting the Laminated Rexine Sheet (Step 2)

Notes: Figure displays a cutter using a hydraulic press to cut hexagons from the laminated rexine sheet. The process for cutting pentagons differs only in the die used.

Figure 4: Printing the Designs (Step 3)

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

Figure 5: Stitching (Step 4)

Notes: Figure displays a worker stitching a soccer ball.

Figure 6: Traditional 2-Hexagon and 2-Pentagon Dies

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

Figure 7: Laminated Rexine Wastage from Cutting Hexagons
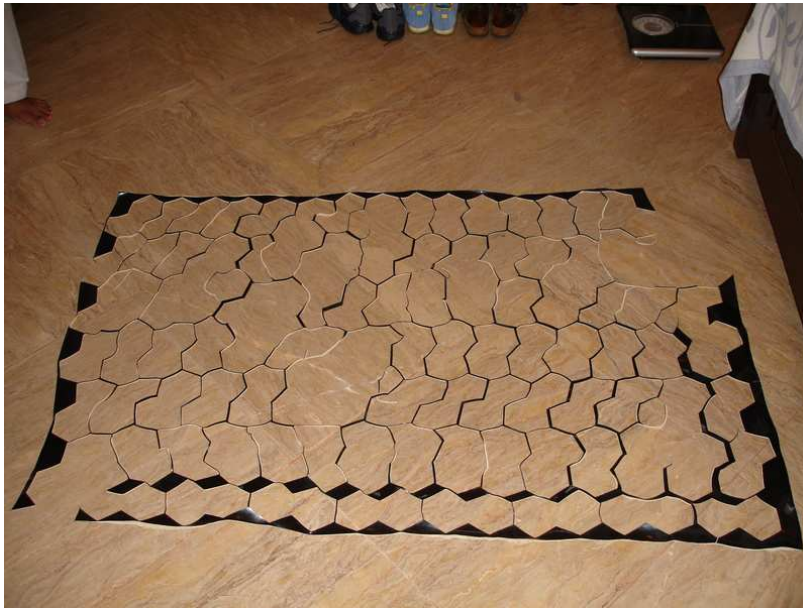
Notes: Figure displays laminated rexine wastage from cutting hexagons with the traditional two-hexagon die.

Figure 8: Laminated Rexine Wastage from Cutting Pentagons

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

Figure 9: Snapshot from YouTube Video of Adidas Jabulani Production Process

Notes: YouTube video available at http://www.youtube.com/watch?v=zbLjk4OTRdI. Accessed June 10, 2011.

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سٹینڈرڈ سائز 5 بال کو 54 انچ بائی 39.5 انچ شیٹ پر بہترین ڈائی کٹ کیلیے طریقہ کار اس طرح درج ذیل ہے

</div>

Figure 10: Cutting Pattern for "Offset" Four-Pentagon Die
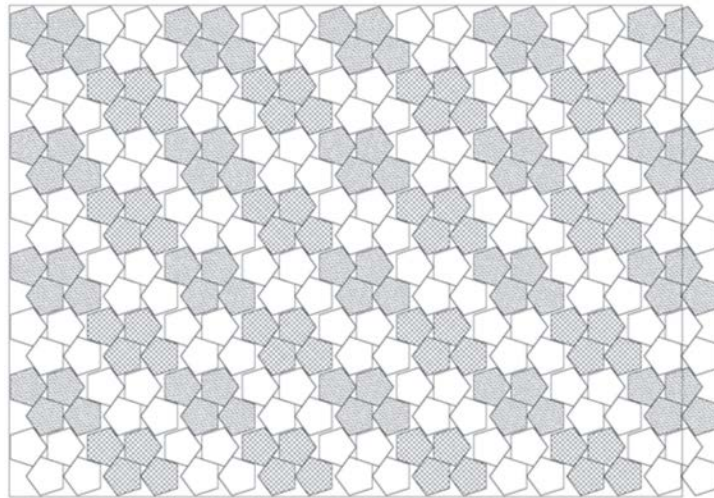
Notes: Figure displays the cutting pattern for the four-panel offset die.

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یہ بہت اہم ہے کہ کٹس (اور کناروں) کا درمیانی فاصلہ کم سے کم ہونا چاہیے (جیسے 2-1 ملی میٹر)۔ ڈائی ریگزین کے دائیں والی سائڈ کے کناروں سے آگے جائی گی لیکن اگر اسے صحیح طرح استعمال کیا جائے تو یہ ممکن ہے کہ دائیں کنارے سے 2 پینٹاگون اضافی مل سکیں گے۔ یہ بات نوٹ کر لیں کہ ڈائی کا سب سے بایاں کنارہ اور سب سے دایاں کنارہ ہر کٹ میں بالکل عمود (سیدھے) ہیں۔

اگر اس کو صحیح طرح استعمال کیا جائے تو یہ ڈائی فی 54 انچ بائی 39.5 انچ ریگزین شیٹ ایک سٹینڈرڈ سائز 5 بال کیلیے 272 پینٹاگون تیار کر سکتی ہے۔ بنیادی ڈیزائن، اور پورے والے ڈائی ڈیزائن میں مختلف X کی ویلیو ڈال کر چھوٹے بال کیلیے پینٹاگون کاٹنے کے کام آ سکتا ہے۔

ریسرچ ٹیم جس نے یہ ڈائی تیار کی ہے وہ اس طرح ہے

ڈاکٹر ڈیوڈ اٹکین (Yale University)، ڈاکٹر اعظم چودھری (Lahore School of Economics)، پروفیسر شاملہ چودھری (Lahore School of Economics)،

ڈاکٹر امیت کھنڈیوال (Columbia Gradute School of Business)، اور ڈاکٹر ایرک ورہوگن (Columbia University)۔

کسی بھی معلومات کی صورت میں براۓ کرم پروفیسر شاملہ چودھری (Lahore School of Economics) سے رابطہ کریں۔

ای میل: shamyla@lahoreschool.edu.pk، رابطہ نمبر: 0300-8096004۔

</div>

Figure 11: Blueprint for "Offset" Four-Pentagon Die
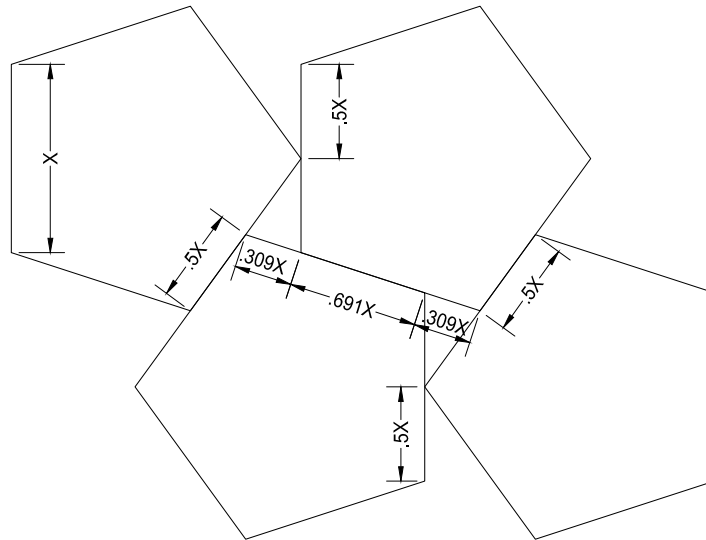
Notes: Figure displays blueprint of the four-panel offset die that was provided to Tech-Drop firms. Blueprint contained instructions for modifying size of die.

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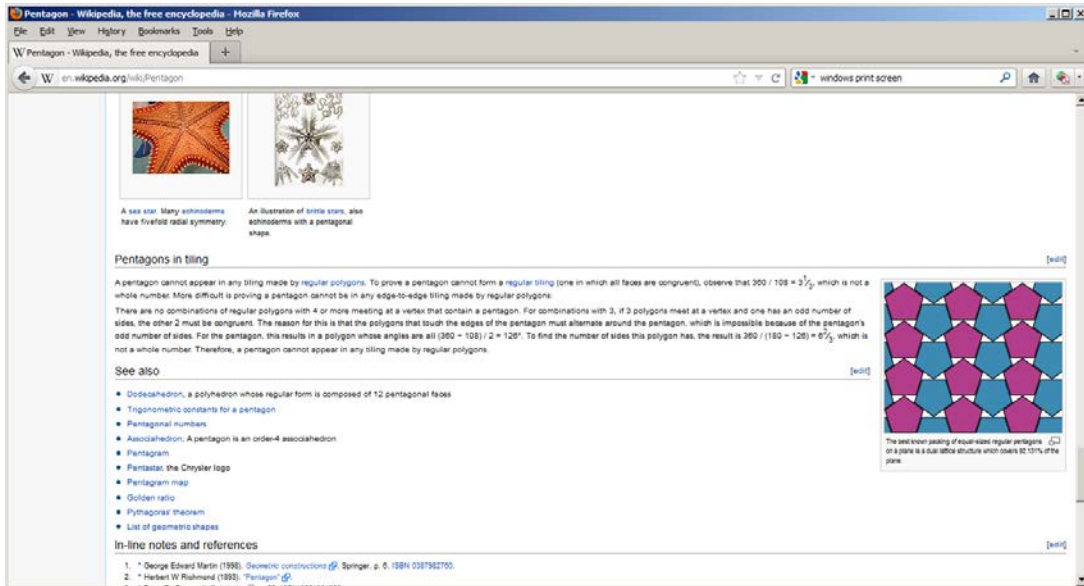
Notes: Figure displays the Wikipedia "Pentagon" page. Accessed April 29, 2012.

Figure 14: Adoption of Offset Dies by Firm Z
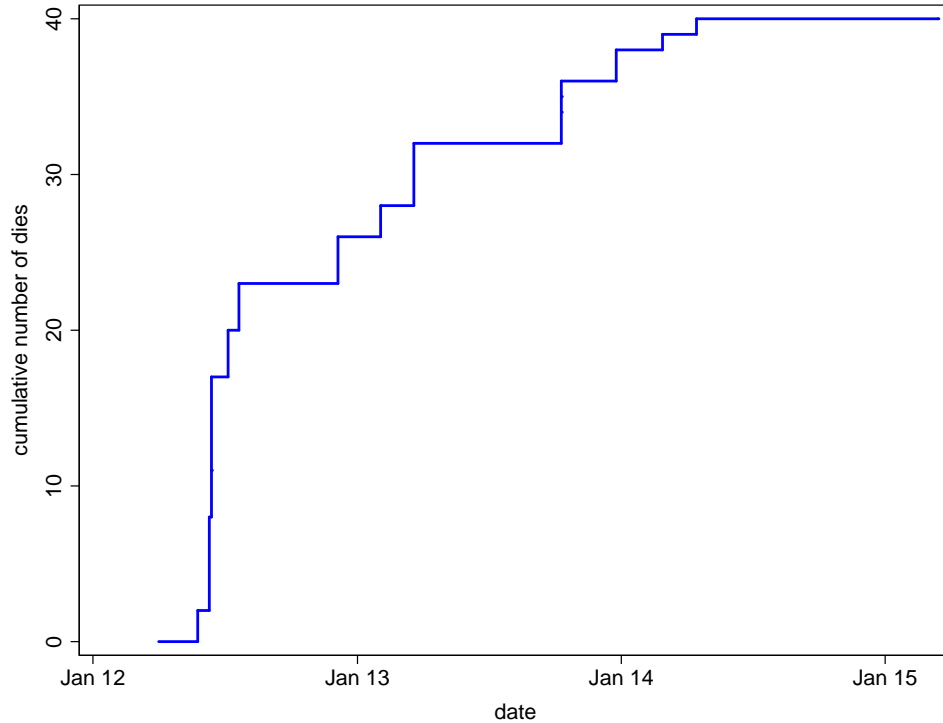
Notes: Figure displays cumulative number of purchases of offset dies by a large producer which was a late responder assigned to the no-drop group, but found out almost immediately about the offset die after the initial roll-out in May 2012. By March 2014 the firm reported using offset dies for 100 percent of its pentagon cutting.

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Figure 15: Permutation Test: Liberal Adoption Measure
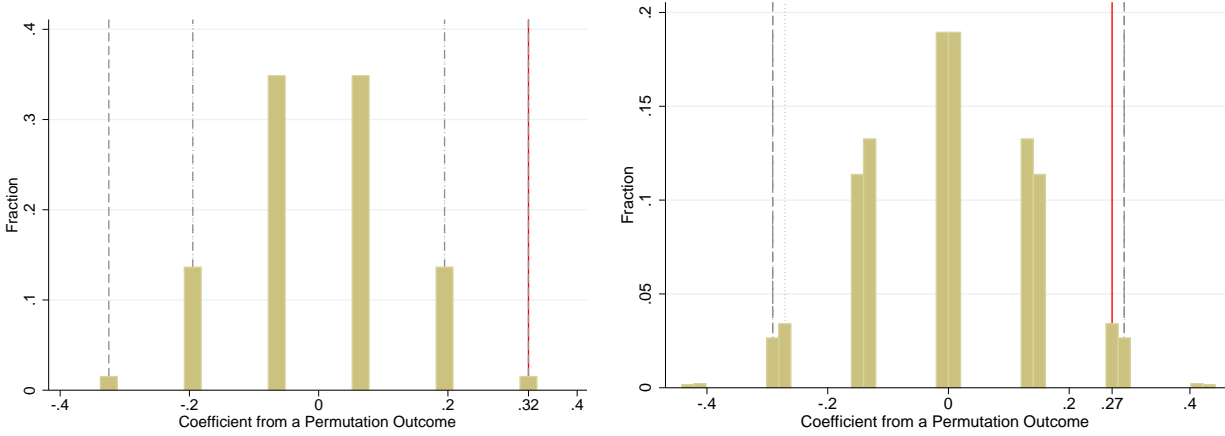
Round 6 (Short Run)   Round 7 (Medium Run)

Notes: Figure displays the distribution of ITT coefficients from short-run (left panel) and medium-run (right panel) permutation tests using the liberal adoption measure (> 1000 balls cut with offset die, using non-survey as well as survey information). The dotted, dashed-dotted and dashed grey lines reflect critical values for a two-sided hypothesis test of the null that that the ITT effect is zero at a 10%, 5% and 1% level of significance, respectively. The solid red line is the observed ITT estimate from Table 11 and is marked on the x-axis to two decimal places. In the left panel, the 10% and 5% lines overlap at both tails, and the 1% line overlaps with the observed ITT estimate at the right tail. In the right panel, the 1% and 5% lines overlap, and the actual ITT estimate overlaps with the 10% line at the right tail.

Figure 16: Permutation Test: Conservative Adoption Measure
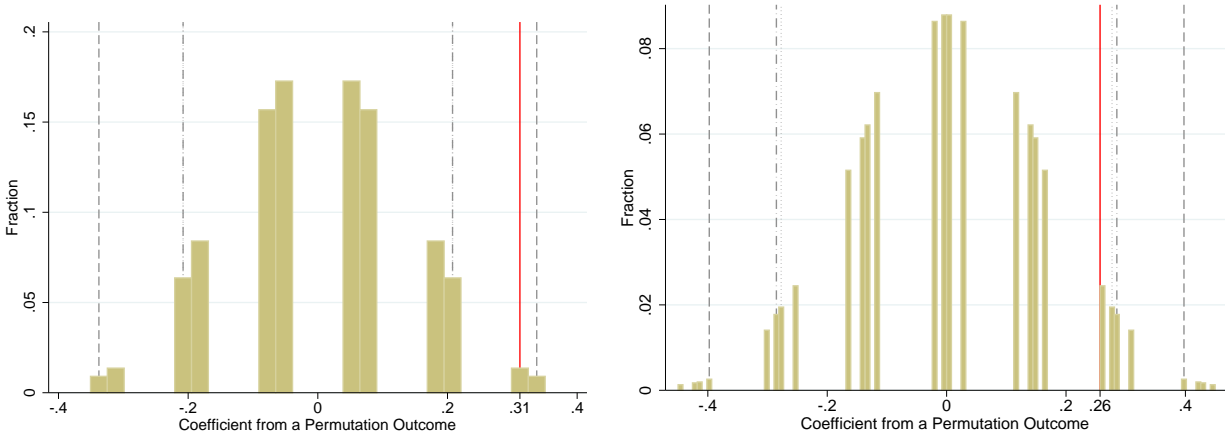
Round 6 (Short-Run)   Round 7 (Medium-Run)

Notes: Figure displays the distribution of ITT coefficients from short-run (left panel) and medium-run (right panel) permutation tests using the conservative adoption measure (> 1000 balls cut with offset die, using only survey information). The dotted, dashed-dotted and dashed grey lines reflect critical values for a two-sided hypothesis test that the ITT effect is zero at a 10%, 5% and 1% level of significance, respectively. The solid red line is the observed ITT estimate from Table 12 and is marked on the x-axis to two decimal places. The 10% and 5% lines overlap in the left panel.

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Figure 17: Permutation Test: Die Purchase

Round 6 (Short-Run)   Round 7 (Medium-Run)
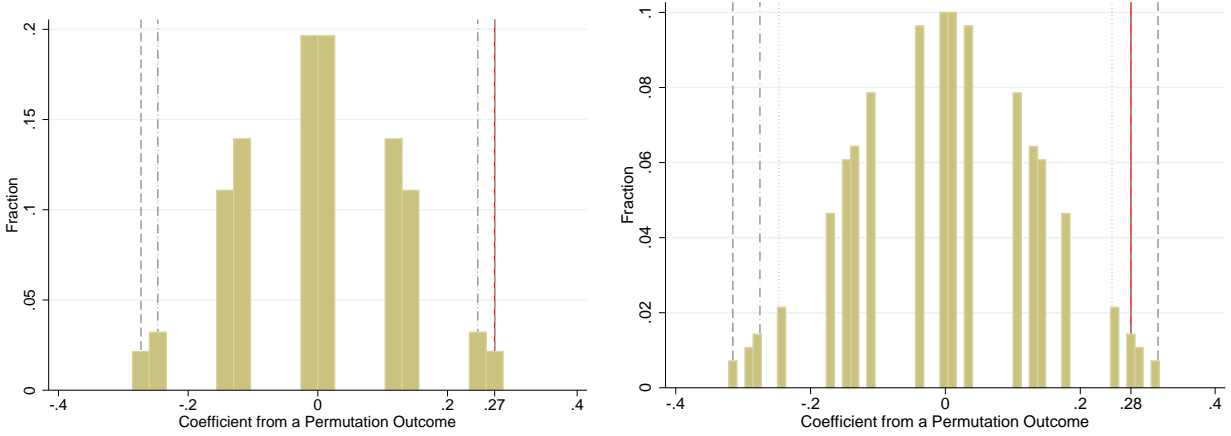
Notes: Figure displays the distribution of ITT coefficients from short-run (left panel) and medium-run (right panel) permutation tests using die purchase after Sept. 2013 as an alternative measure of adoption. The dotted, dashed-dotted and dashed grey lines reflect critical values for a two-sided hypothesis test that the ITT effect is zero at a 10%, 5% and 1% level of significance, respectively. The solid red line is the observed ITT estimate from Table 13 and is marked on the x-axis to two decimal places. In the left panel, the 10% and 5% lines overlap at both tails, and the observed ITT estimate overlaps with the 1% line at the right tail. In the right panel, the 5% line overlaps with the actual ITT estimate at the right tail.

Figure 18: Implied Bounds on Fixed Costs Under a Learning Subsidy Explanation
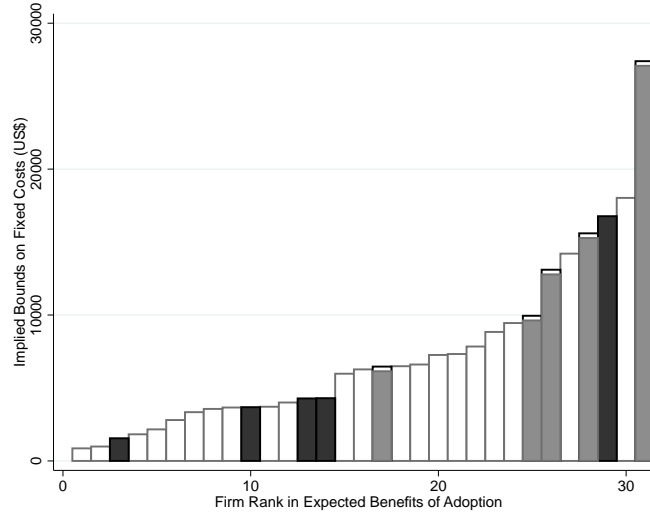
Notes: Figure displays implied bounds on fixed costs for each firm in incentive-payment intervention, assuming a 25 percent per year interest rate and a prior that the technology works of 0.5 (see Section 9.1). The solid black bars indicate upper bounds on fixed costs for the initial adopters, and the white bars indicate lower bounds for the never-adopters. The solid grey bars indicate lower bounds for initial non-adopters that adopted in response to the incentive treatment (Experiment-2 compliers); the black outlines above the solid grey bars indicate upper bounds for these firms (i.e. unobserved fixed costs can simultaneously explain both initial non-adoption and subsequent adoption for these firms only if they fall between top of grey bar and black outline.)

Table 1: Pentagons per Sheet

	traditional die		offset die	
	owner report (1)	direct obs. (2)	owner report (3)	direct obs. (4)
size 43.5	257.3	257.7	273.5	277.5
	(10.6)	(6.7)	(4.4)	(5.3)
size 43.75	256.3	254.4	269.0	272.0
	(6.7)	(9.4)	(1.4)	(0.0)
size 44	254.3	248.4	280.0	272.5
	(9.1)	(18.7)		(0.7)
size 44.25	246.1	262.0	272.0	
	(8.3)			
rescaled (to size 44)	254.2	248.3	280.0	275.4
	(8.9)	(11.0)	(3.0)	(4.8)
N (all sizes)	320	39	8	10

 Notes: Table reports average pentagons per sheet by die size. Column 1 indicates self-reported numbers from the owner, several rounds per firm in some cases. Column 2 indicates pentagons per sheet directly observed by the survey team for tech-drop firms (during the initial cutting demonstration) and for cash-drop firms (at the time of the cash drop — we did not demonstrate the offset die at these firms but did ask them to cut one sheet of hexagons and one of pentagons). Columns 3-4 report numbers for the offset die and were only collected from tech-drop firms. In the fifth row, pentagons per sheet are rescaled using means for each size in each column. The final row reports 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	0.78	1.49
	(0.22)	(0.31)
labor for stitching	19.67	39.24
	(5.25)	(12.82)
other labor	7.30	15.56
	(4.55)	(13.21)
overhead	5.14	10.84
	(2.05)	(6.10)
total	100.00	210.83
N	38	38

Notes: Columns 1 and 2 report the mean cost share per ball of each input and the input cost in Rupees, respectively. "Other labor" includes laminating, washing, packing, and matching. Data taken from the baseline survey. Standard deviations in parentheses.

	10th	25th	50th	75th	90th	mean
A. Variable cost reduction from reduced waste of material						
reduction in pentagon laminated rexine cost (%)	4.18	5.35	6.84	7.47	11.23	6.85
	(0.40)	(0.49)	(0.19)	(0.05)	(1.02)	(0.18)
laminated rexine as share of total cost (%)	34.79	39.86	44.70	51.22	55.39	45.91
	(1.16)	(0.74)	(0.63)	(0.48)	(0.89)	(0.69)
variable cost reduction (%)	0.58	0.75	0.98	1.21	1.67	1.04
	(0.03)	(0.04)	(0.02)	(0.06)	(0.13)	(0.03)
B. Variable cost increase from increased labor time						
cutter wage as share of cost (%)	0.30	0.36	0.46	0.59	0.72	0.48
	(0.01)	(0.00)	(0.01)	(0.01)	(0.02)	(0.01)
variable cost increase (%)	0.05	0.06	0.08	0.10	0.12	0.08
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
C. Net benefits						
net variable cost reduction (%)	0.49	0.67	0.90	1.13	1.60	0.96
	(0.03)	(0.04)	(0.03)	(0.06)	(0.13)	(0.03)
% net variable cost/avg % profit rate	5.08	7.62	11.33	17.92	26.15	14.11
	(0.35)	(0.49)	(0.66)	(0.99)	(2.25)	(0.61)
total cost savings per month (Rs 000s)	3.96	10.62	45.36	144.58	415.53	147.94
	(0.45)	(1.10)	(4.63)	(15.80)	(65.03)	(14.75)
days to recover fixed costs	9.40	17.32	38.55	89.23	206.78	146.30
	(1.02)	(1.44)	(2.70)	(8.18)	(19.33)	(37.18)
days to recover fixed costs (no die)	4.88	9.00	20.02	46.33	107.37	75.96
	(0.53)	(0.75)	(1.40)	(4.25)	(10.04)	(19.31)

Notes: Each row reports the distribution across firms of the variable indicated in that row. The 1st row reports the reduction in the cost of laminated rexine to cut pentagons. The 2nd row reports the cost of laminated rexine as a percentage of total unit costs. The 3rd row reports the variable cost reduction from adopting the offset die, computed as the product of a firm's reduction in laminated rexine costs to cut pentagons, laminated rexine's share of total cost, and 33 percent (the share of pentagons relative to hexagons in total laminated rexine costs). The 4th row reports the cutter's wage as a share of unit costs. The 5th row is an estimate of the percentage increase in variable labor cost from adopting the offset die, calculated as 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 the tech-drop firms that received the die for free. As noted in the text, the table uses 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. Since the late responder sample was not asked laminated rexine share of costs (Row 2) at baseline, we draw from the empirical distribution of the full sample of initial-responder firms. We repeat this process 1,000 times and report the mean and standard deviations (in parentheses) of each statistic.

Table 4: Firm Characteristics by Quantile

	Mean	Min	10th	25th	50th	75th	90th	Max	N
A. Initial-responder sample									
avg output/month (000s)	31.2	0.8	1.5	3.2	10.0	34.1	71.7	275.0	85
avg employment	89.8	4.0	5.6	7.4	18.3	50.0	235.0	1,700.0	85
avg employment (cutters)	5.6	0.7	1.0	1.0	2.2	5.0	12.0	123.0	85
avg Rs/ball (head cutter)	1.5	1.0	1.2	1.3	1.5	1.6	1.9	2.9	79
avg % size 5	89.4	52.4	68.1	84.0	94.0	100.0	100.0	100.0	85
avg % size 4	3.1	0.0	0.0	0.0	0.0	4.1	7.8	35.0	85
avg % size other	7.5	0.0	0.0	0.0	1.7	11.2	20.0	47.6	85
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	243.1	152.5	185.0	200.0	231.2	269.1	300.0	575.0	64
avg price, size 5 training	441.3	200.0	275.0	316.7	392.5	490.0	600.0	2,250.0	73
avg profit %, size 5 promo	8.1	2.6	3.9	5.0	7.9	10.2	12.5	20.0	64
avg profit %, size 5 training	7.9	1.6	3.2	4.6	7.8	9.9	11.8	22.2	71
avg % lamination in-house	95.7	31.2	81.2	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)	33.4	0.0	1.6	4.6	15.2	37.0	86.2	275.0	116
avg employment	103.2	4.0	6.0	8.2	24.9	75.0	227.0	2,180.0	115
avg employment (cutters)	5.2	0.7	1.0	1.2	2.4	5.0	12.0	123.0	115
avg Rs/ball (head cutter)	1.6	1.0	1.1	1.3	1.5	1.7	2.1	3.0	108
avg % size 5	88.6	42.8	64.2	83.3	94.4	100.0	100.0	100.0	115
avg % size 4	2.5	0.0	0.0	0.0	0.0	3.3	6.0	35.0	115
avg % size other	8.9	0.0	0.0	0.0	2.2	13.3	31.9	57.2	115
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	248.6	150.0	185.0	205.0	236.7	270.0	310.0	575.0	83
avg price, size 5 training	465.3	200.0	300.0	335.2	400.0	508.2	662.5	2,250.0	102
avg profit (%), size 5 promo	8.1	2.6	3.9	5.0	7.4	10.4	13.6	20.0	82
avg profit (%), size 5 training	8.1	1.6	3.2	5.0	8.0	10.0	13.0	22.2	98
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 contains firms that responded to baseline survey. Piece rate and prices are in Rupees (exchange rate is approximately 100 Rs/US$1). Size 5 is regulation size for adults; size 4 is commonly used by children; "avg % size other" refers to sizes 1, 2, and 3. Age, experience and tenure are in years.

Table 5: Treatment Assignment, Tech-Drop Experiment

	# Firms			
	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. Initial non-responders				
active, late response	12	5	14	31
active, refused all surveys	0	1	15	16
inactive (revealed not to be a producer)	7	3	12	22

 Notes: Table reports numbers of firms by treatment assignment among initial responders (Panel A) and initial non-responders (Panel B). Active firms are those who had produced soccer balls in the previous 12 months and cut their own laminated rexine. The last row reports numbers of firms included in the initial randomization that we believed were firms (based on an initial listing exercise) but that did not respond to the baseline survey and were later revealed not to be soccer-ball producers, because (a) they shifted entirely to other products, (b) they had gone out of business, or (c) they were not cutting their own laminated rexine.

Table 6: Covariate 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	1.62	1.37
	(0.14)	(0.21)	(0.10)
N	23	12	50
B. Late responders			
output, normal month (000s)	27.85	34.80	63.12
	(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)	(3.12)
% promotional (of size 5)	31.17	36.11	24.22
	(9.77)	(12.58)	(13.28)
age of firm	17.40	39.60	35.12
	(3.13)	(16.68)	(5.55)
N	10	5	8

Notes: Table reports balance for initial responders (i.e. responders to baseline) (Panel A) and late responders (Panel B). There are no significant differences between groups at the 95 percent level in the initial responder sampler. The late responder sample has significant differences, consistent with the observation that response rates responded to treatment assignment among initial non-adopters. Standard errors 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, conservative)	3	0	0	3
# ever used new die (>1000 balls, liberal)	4	0	0	4
B. Full sample				
# ever active firms	35	18	79	132
# ever responded	35	17	64	116
# currently active and ever responded	32	15	59	106
# traded in	19	0	0	19
# ordered new die (beyond trade-in)	1	0	6	7
# received new die (beyond trade-in)	1	0	4	5
# ever used new die (>1000 balls, conservative)	4	0	1	5
# ever used new die (>1000 balls, liberal)	5	0	1	6

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 the 5th and 6th rows is that one diemaker was particularly slow in delivering offset dies and firms subsequently canceled their orders. The 7th row indicates adoption statistics using the "conservative" definition: the number of firms that produced at least 1,000 balls as of August 2013 based on survey data. The 8th row indicates adoption statistics using the "liberal" definition, which combines survey data and field reports from our enumerators.

Table 8: Reasons for Non-Adoption (Tech Drop Firms), as of Aug. 2013

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		2			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					1			3

Notes: Table reports responses from the March–April 2013 survey round of the 18 tech-drop firms that responded to the question "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]."

Table 9: Covariate Balance, Incentive-Payment Experiment

	Group A Incentive Contract (1)	Group B No Incentive Contract (2)	Difference (3)
log avg output/month	9.86	9.31	0.55
	(0.41)	(0.29)	(0.50)
log avg employment	3.35	3.23	0.13
	(0.38)	(0.25)	(0.45)
log avg price, size 5 promo	5.40	5.45	-0.05
	(0.02)	(0.07)	(0.07)
log avg price, size 5 training	6.00	5.93	0.07
	(0.06)	(0.06)	(0.08)
avg % promotional (of size 5)	34.90	32.04	2.86
	(6.20)	(7.26)	(9.60)
avg Rs/ball, head cutter	1.45	1.63	-0.17
	(0.10)	(0.15)	(0.18)
CEO university indicator	0.56	0.36	0.19
	(0.18)	(0.15)	(0.23)
CEO experience	15.50	16.50	-1.00
	(3.60)	(3.60)	(5.13)
age of firm	24.53	20.60	3.93
	(2.83)	(2.28)	(3.64)
N	15	16	31

 Notes: Table reports baseline balance in the Incentive-Payment Experiment (Experiment 2). The sample is the 31 tech-drop firms from the Tech-Drop Experiment who were active as of September 2013. There are no significant differences between treatment and control groups. Standard errors in parentheses.

Table 10: "Test" Results

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

 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 and seconds, to cut a single laminated 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. The typical time to cut a sheet with the traditional die is 2:15.

Table 11: Incentive-Payment Experiment (Liberal Adoption Measure)

Panel A: Short-Run (as of Round 6)

| | Dep. var.: adoption ($>$1,000 balls, liberal measure) | | | |
	First Stage (1)	OLS (2)	Reduced Form (ITT) (3)	IV (TOT) (4)
received treatment		0.48***		0.48***
		(0.15)		(0.15)
assigned to group A	0.68***		0.32**	
	(0.12)		(0.12)	
stratum dummies	Y	Y	Y	Y
R-squared	0.57	0.69	0.60	0.69
N	31	31	31	31

Panel B: Medium-Run (as of Round 7)

| | Dep. var.: adoption ($>$1,000 balls, liberal measure) | | | |
	First Stage (1)	OLS (2)	Reduced Form (ITT) (3)	IV (TOT) (4)
received treatment		0.41**		0.37**
		(0.16)		(0.17)
assigned to group A	0.72***		0.27*	
	(0.12)		(0.14)	
stratum dummies	Y	Y	Y	Y
R-squared	0.60	0.61	0.52	0.61
N	29	29	29	29

Notes: Table reports results of incentive-payment experiment on adoption rates using the liberal definition of adoption. Panel A reports short-run results as of Round 6 (Jan.-March 2014). Panel B reports medium-run results as of Round 7 (Oct.-Dec. 2014). The dependent variable in Column 1 is an indicator variable for whether the firm received treatment. The number of observations differ between rounds because two firms exited between Rounds 6 and 7. All regressions include stratum dummies, and report robust standard errors. Significance: * 0.10, ** 0.05; *** 0.01.

Table 12: Incentive-Payment Experiment (Conservative Adoption Measure)

	Panel A: Short-Run (as of Round 6)			
		Dep. var.: adoption (>1,000 balls, cons. measure)		
	First Stage (1)	OLS (2)	Reduced Form (ITT) (3)	IV (TOT) (4)
received treatment		0.45*** (0.16)		0.46*** (0.16)
assigned to group A	0.68*** (0.12)		0.31** (0.12)	
stratum dummies	Y	Y	Y	Y
R-squared	0.57	0.56	0.46	0.56
N	31	31	31	31

	Panel B: Medium-Run (as of Round 7)			
		Dep. var.: adoption (>1,000 balls, cons. measure)		
	First Stage (1)	OLS (2)	Reduced Form (ITT) (3)	IV (TOT) (4)
received treatment		0.39** (0.17)		0.35* (0.19)
assigned to group A	0.72*** (0.12)		0.26* (0.14)	
stratum dummies	Y	Y	Y	Y
R-squared	0.60	0.46	0.38	0.45
N	29	29	29	29

Notes: Table reports results of incentive-payment experiment on adoption rates using the conservative definition of adoption. Panel A reports short-run results as of Round 6 (Jan.-March 2014). Panel B reports medium-run results as of Round 7 (Oct.-Dec. 2014). The dependent variable in Column 1 is an indicator variable for whether the firm received treatment. The number of observations differ between rounds because two firms exited between Rounds 6 and 7. All regressions include stratum dummies, and report robust standard errors. Significance: * 0.10, ** 0.05; *** 0.01.

Table 13: Incentive-Payment Experiment Results (Die Purchase as Outcome)

Panel A: Short-Run (as of Round 6)

	First Stage (1)	OLS (2)	Reduced Form (ITT) (3)	IV (TOT) (4)
		Dep. var.: purchased offset die after 9/1/2013		
received treatment		0.42**		0.40**
		(0.15)		(0.16)
assigned to group A	0.68***		0.27**	
	(0.12)		(0.12)	
stratum dummies	Y	Y	Y	Y
R-squared	0.57	0.40	0.24	0.40
N	31	31	31	31

Panel B: Medium-Run (as of Round 7)

	First Stage (1)	OLS (2)	Reduced Form (ITT) (3)	IV (TOT) (4)
		Dep. var.: purchased offset die after 9/1/2013		
received treatment		0.41**		0.38**
		(0.15)		(0.16)
assigned to group A	0.72***		0.28**	
	(0.12)		(0.12)	
stratum dummies	Y	Y	Y	Y
R-squared	0.60	0.40	0.24	0.40
N	29	29	29	29

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. Panel A reports short-run results as of Round 6 (Jan.-March 2014). Panel B reports medium-run results as of Round 7 (Oct.-Dec. 2014). The dependent variable in Column 1 is an indicator variable for whether the firm received treatment. The number of observations differ between rounds because two firms exited between Rounds 6 and 7. All regressions include stratum dummies, and report robust standard errors. Significance: * 0.10, ** 0.05; *** 0.01.

Table 14: Quantitative Plausibility of Learning-Subsidy Explanation

	Value of prior					
	.01 (1)	.05 (2)	.1 (3)	.25 (4)	.5 (5)	1 (6)
A. Estimates of fixed costs						
estimate of μ	6.47***	7.41***	8.00***	8.85***	9.53***	10.21***
	(0.51)	(0.31)	(0.29)	(0.28)	(0.28)	(0.28)
estimate of σ_ε	1.89**	1.31**	1.25***	1.22***	1.22***	1.22***
	(0.75)	(0.49)	(0.44)	(0.41)	(0.41)	(0.41)
N	31	31	31	31	31	31
B. ITT estimate						
assigned to group A	0.24	0.10	0.06	0.02	0.01	0.01
	(0.11)	(0.08)	(0.07)	(0.04)	(0.03)	(0.02)
N	31	31	31	31	31	31
C. P-values of observing ≥ 5 adopters in incentive experiment						
	0.219	0.011	0.001	0.000	0.000	0.000

Notes: Sample is tech-drop firms still active at the time of second experiment (Sept. 2013). Panel A reports estimates for μ and σ_ε from maximizing the likelihood function in (10) for the value of prior noted in the column heading. Panel B reports the average and standard deviation of the ITT estimates across 1000 simulation draws of log fixed costs from a normal distribution with mean $\hat{\mu}$ and standard deviation $\hat{\sigma}_\varepsilon$ for the corresponding prior. Panel C reports the p-values of observing 5 or more adopters in the short-run (recall that we observed 5 adopters in the short-run according to the liberal-definition adoption variable), based on the frequency of occurrence in the 1000 simulations, under the null hypothesis that second experiment only changed fixed costs. Significance: * 0.10, ** 0.05, *** 0.01.

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

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A   Theory appendix

A.1   Preliminaries

As a preliminary step, we first establish several properties of the profit functions defined in (2).

Lemma 1. *Given the definition of $\pi_i(\cdot)$ in (2) and condition (5a), we have:*

$$
\pi_2(\beta) - \pi_0(\beta) \begin{cases} < 0 & \text{if } 0 < \beta < \hat{\beta}_2 \\ = 0 & \text{if } \beta = \hat{\beta}_2 \\ > 0 & \text{if } \beta > \hat{\beta}_2 \end{cases}
$$

where $\hat{\beta}_2 = \Omega + \sqrt{\Omega^2 + \frac{F}{s_0{}^2 - s_2{}^2}}$, $\Omega = \frac{s_0^2 \beta_0 - s_2^2 \beta_2}{s_0^2 - s_2^2}$, $\hat{\beta}_2 > \Omega$, and $0 < \hat{\beta}_2 < \beta_0$, with β_0 and β_2 as defined in (3).

Proof. From (2), we can write:

$$
\pi_2(\beta) - \pi_0(\beta) = \left(s_0{}^2 - s_2{}^2\right)(\beta - \Omega)^2 - \Omega^2 \left(s_0{}^2 - s_2{}^2\right) - F \tag{A1}
$$

This defines a convex parabola with vertex at $\left(\Omega, -\Omega^2 \left(s_0{}^2 - s_2{}^2\right) - F\right)$. Note that $\Omega < \beta_0$ and may be negative. Setting $\pi_2(\beta) - \pi_0(\beta) = 0$ gives two critical values of β. Since we are requiring $\beta > 0$, we ignore the negative root. The positive root defines the value of $\hat{\beta}_2$. The fact that $\hat{\beta}_2 > \Omega$ follows immediately from the expression for $\hat{\beta}_2$. The fact that $\hat{\beta}_2 < \beta_0$ follows from condition (5a). $\square$

Lemma 2. *Given the definition of $\pi_i(\cdot)$ in (2) and condition (5b), we have:*

$$
\pi_3(\beta) - \pi_0(\beta) \begin{cases} < 0 & \text{if } \beta < \hat{\beta}_3 \\ = 0 & \text{if } \beta = \hat{\beta}_3 \\ > 0 & \text{if } \hat{\beta}_3 < \beta < \hat{\hat{\beta}}_3 \\ = 0 & \text{if } \beta = \hat{\hat{\beta}}_3 \\ < 0 & \text{if } \beta > \hat{\hat{\beta}}_3 \end{cases}
$$

where $\hat{\beta}_3 = \beta_0 - \sqrt{\beta_0^2 - \frac{F}{s_3{}^2 - s_0{}^2}}$, $\hat{\hat{\beta}}_3 = \beta_0 + \sqrt{\beta_0^2 - \frac{F}{s_3{}^2 - s_0{}^2}}$ and $0 < \hat{\beta}_3 < \beta_0 < \beta_2 < \hat{\hat{\beta}}_3 < 2\beta_0$, with β_0 and β_2 as defined in (3).

Proof. From (2), we can write:

$$
\pi_3(\beta) - \pi_0(\beta) = -\left(s_3{}^2 - s_0{}^2\right)(\beta - \beta_0)^2 + \beta_0^2 \left(s_3{}^2 - s_0{}^2\right) - F \tag{A2}
$$

This defines a concave parabola with vertex at $\left(\beta_0, \beta_0^2 \left(s_3{}^2 - s_0{}^2\right) - F\right)$. Condition (5b) implies that $\pi_3(\beta_0) > \pi_0(\beta_0)$, since $\pi_3(\beta) - \pi_0(\beta)$ is decreasing over $(\beta_0, \beta_2]$, and this in turn implies $\beta_0^2 \left(s_3{}^2 - s_0{}^2\right) - F > 0$. Setting $\pi_3(\beta) - \pi_0(\beta) = 0$ defines the values of the roots, $\hat{\beta}_3$ and $\hat{\hat{\beta}}_3$. The facts that $0 < \hat{\beta}_3 < \beta_0 < \hat{\hat{\beta}}_3 < 2\beta_0$ follow directly from the expressions for $\hat{\beta}_3$ and $\hat{\hat{\beta}}_3$. The fact that $\beta_2 < \hat{\hat{\beta}}_3$ follows from condition (5b). $\square$

Lemma 3. *Given the definition of $\pi_i(\cdot)$ in (2), we have:*

$$\pi_1(\beta) - \pi_0(\beta) \quad \begin{cases} < 0 & \text{if } 0 < \beta < \hat{\hat{\beta}}_1 \\ = 0 & \text{if } \beta = \hat{\hat{\beta}}_1 \\ > 0 & \text{if } \beta > \hat{\hat{\beta}}_1 \end{cases}$$

where $\hat{\hat{\beta}}_1 = \beta_0 + \sqrt{\beta_0^2 + \frac{F}{s_0{}^2 - s_1{}^2}} > 2\beta_0$, with β_0 as defined in (3).

Proof. From (2), we can write

$$\pi_1(\beta) - \pi_0(\beta) = \left(s_0{}^2 - s_1{}^2\right)(\beta - \beta_0)^2 - \left(s_0{}^2 - s_1{}^2\right)\beta_0^2 - F \tag{A3}$$

which is a convex parabola with roots $\hat{\beta}_1 = \beta_0 - \sqrt{\beta_0^2 + \frac{F}{s_0{}^2 - s_1{}^2}} < 0$ and $\hat{\hat{\beta}}_1$ defined above. Since we have assumed $\beta > 0$, $\hat{\beta}_1$ will not play a role. $\square$

Lemma 4. *Given the definition of $\pi_i(\cdot)$ in (2) and conditions (5b) and (5c), we have:*

$$Z(\beta) \equiv \left[\frac{\rho_1}{\rho_1 + \rho_2}\pi_1(\beta) + \frac{\rho_2}{\rho_1 + \rho_2}\pi_2(\beta)\right] - \pi_0(\beta) \quad \begin{cases} < 0 & \text{if } \hat{\beta}_2 \leq \beta < \overline{\beta} \\ = 0 & \text{if } \beta = \overline{\beta} \\ > 0 & \text{if } \beta > \overline{\beta} \end{cases}$$

for some $\overline{\beta} > \beta_0$.

Proof. We first consider $\beta = \beta_0$. By condition (5c), $\pi_0(\beta_0) > \widetilde{\pi}(\widetilde{\beta})$. Since $\widetilde{\beta}$ is the optimal choice if the principal bases her decision only on her priors, it must be the case that $\widetilde{\pi}(\widetilde{\beta}) \geq \widetilde{\pi}(\beta_0)$. Hence $\pi_0(\beta_0) > \widetilde{\pi}(\beta_0)$. This in turn implies:

$$\begin{aligned} \pi_0(\beta_0) &> \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) + \rho_3\pi_3(\beta_0) \\ \pi_0(\beta_0) - \rho_3\pi_3(\beta_0) &> \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) \\ \pi_0(\beta_0) - \rho_3\pi_0(\beta_0) &> \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) \\ (\rho_1 + \rho_2)\pi_0(\beta_0) &> \rho_1\pi_1(\beta_0) + \rho_2\pi_2(\beta_0) \\ 0 &> \left[\frac{\rho_1}{\rho_1 + \rho_2}\pi_1(\beta_0) + \frac{\rho_2}{\rho_1 + \rho_2}\pi_2(\beta_0)\right] - \pi_0(\beta_0) = Z(\beta_0) \end{aligned} \tag{A4}$$

where the third inequality follows from the fact that $\pi_3(\beta_0) > \pi_0(\beta_0)$ (from condition (5b)).

Now consider $\beta \in [\hat{\beta}_2, \beta_0)$. Note that:

$$Z(\beta) = \frac{\rho_1[\pi_1(\beta) - \pi_0(\beta)] + \rho_2[\pi_2(\beta) - \pi_0(\beta)]}{\rho_1 + \rho_2} \tag{A5}$$

By Lemma 3, $\pi_1(\beta) - \pi_0(\beta) < 0$ in this region. From (A1), $\pi_2(\beta) - \pi_0(\beta)$ is strictly increasing over this region. Hence if $Z(\beta_0) < 0$ then must be the case that $Z(\beta) < 0$ for all $\beta \in [\hat{\beta}_2, \beta_0)$.

Now consider $\beta > \beta_0$. Using (A1), (A3) and (A5), we have:

$$\frac{\partial Z(\beta)}{\partial \beta} = \frac{1}{\rho_1 + \rho_2}\left[2\rho_1\left(s_0{}^2 - s_2{}^2\right)(\beta - \Omega) + 2\rho_2\left(s_0{}^2 - s_1{}^2\right)(\beta - \beta_0)\right]$$

which is strictly positive and increasing in β for $\beta > \beta_0$ (noting that $\Omega < \hat{\beta}_2 < \beta_0$). Since $Z(\beta)$ is

negative at β_0 and has strictly positive and increasing slope for $\beta > \beta_0$, it takes the value zero at a single point, call it $\overline{\beta}$, and is negative for $\beta \in (\beta_0, \overline{\beta})$ and positive for $\beta \in (\overline{\beta}, \infty)$.[1] $\qquad\square$

A.2 Proof of Proposition 1

We proceed in three steps. In subsection A.2.1, we consider the subgame for any value of β. We show that there are at most two possible equilibria in each subgame, an informative one and a "babbling" one (modulo treating "essentially equivalent" messages as identical). In subsection A.2.2, we consider the particular subgame with $\beta = \beta_0$ (where β_0 is defined in (3)) and calculate the principal's payoff in the informative equilibrium of that subgame. In subsection A.2.3, we consider the principal's choice of β in the main game. We show that the principal's payoff in the informative equilibrium of the subgame with $\beta = \beta_0$ dominates the highest possible payoffs in all equilibria of all other subgames and hence that the strategies described in Proposition 1 form an equilibrium. This equilibrium is particularly salient in that it exists even if the most informative equilibrium holds in the subgame for every β.

A.2.1 Subgames conditional on β

Conditional on β, the setting is a discrete version of the setting considered by Crawford and Sobel (1982) (hereafter CS). Let Θ be the set of possible new technologies (i.e. $\{\theta_1, \theta_2, \theta_3\}$). We refer to an agent who observes θ_i as being "type θ_i." Let m be a message and M the set of possible messages. Let $q(m|\theta)$ be the agent's probability of sending signal m if the technology is revealed to be type θ, where $\sum_{m \in M} q(m|\theta) = 1$ for each θ. Let $\rho(\theta)$ be the principal's prior distribution; that is, $\rho(\theta_1) = \rho_1$, $\rho(\theta_2) = \rho_2$, $\rho(\theta_3) = \rho_3$. Let $a(m) \in [0, 1]$ be the probability of adoption by the principal in response to the message m. Let $\widehat{U}(a(m), \beta, \theta)$ be the expected utility of the agent of type θ, prior to the adoption decision of the principal:

$$\widehat{U}(a, \beta, \theta_i) = aU(\beta, \theta_i) + (1-a)\left(\frac{\beta^2 s_0^2}{2}\right) = a\left(\frac{\beta^2 s_i^2}{2}\right) + (1-a)\left(\frac{\beta^2 s_0^2}{2}\right) \tag{A6}$$

where $U(\cdot, \cdot)$ is as defined in (1) and $\frac{\beta^2 s_0^2}{2}$ is the agent's utility under the existing technology. Let $\widehat{\pi}(a, \beta, \theta_i)$ be the expected profit of the principal prior to the adoption decision, conditional on θ_i (which at this stage is unknown to the principal):

$$\begin{aligned} \widehat{\pi}(a, \beta, \theta_i) &= a\pi_i(\beta) + (1-a)\pi_0(\beta) \\ &= a\left[s_i^2\beta\left(p - \beta - c_i\right) - F\right] + (1-a)\left[s_0^2\beta\left(p - \beta - c_0\right)\right] \end{aligned} \tag{A7}$$

where $\pi_i(\cdot)$ is as defined in in (2). The principal's posterior beliefs after receiving signal m, by Bayes' rule, are:

$$p(\theta|m) = \frac{q(m|\theta)\rho(\theta)}{\sum_{\theta' \in \Theta} q(m|\theta')\rho(\theta')}$$

An equilibrium is a family of signaling rules $q(m|\theta)$ for the agent (sender) and an action rule $a(m)$ for the principal (receiver) such that the following conditions hold:

1. If $q(m^*|\theta) > 0$ then

$$m^* = \arg\max_{m \in M} \widehat{U}(a(m), \beta, \theta) \tag{A8}$$

---

[1]To see this, note that $Z(\beta) = \int_c^\beta Z'(\beta')d\beta' + C$ for some finite constants c and C. Hence, $\lim_{\beta \to \infty} Z(\beta) = \int_c^\infty Z'(\beta')d\beta' + C$. Since $Z'(\beta')$ does not go to zero as β' goes to infinity, $Z(\beta) \longrightarrow \infty$ and so must cross zero.

2. For each m,

$$a(m) = \arg\max_{a \in [0,1]} \sum_{\theta \in \Theta} \widehat{\pi}(a, \beta, \theta) p(\theta|m) \tag{A9}$$

That is, the rule of each player must be a best response to the rule of the other player. Following CS, we describe two messages m and m' as *essentially equivalent* in a given equilibrium if they induce the same action, that is $a(m) = a(m')$. Let $M_a = \{m : a(m) = a\}$ be the set of essentially equivalent messages that lead the principal to choose action a (i.e., adopt with probability a). Following CS, we say that an action a is *induced* by an agent of type θ if $\sum_{m \in M_a} q(m|\theta) > 0$.

For a given equilibrium, let $m_{min} = \arg\min_{m \in M} a(m)$ and $m_{max} = \arg\max_{m \in M} a(m)$ be messages that induce the lowest and highest probabilities of adoption, respectively. Let $a_{min} \equiv a(m_{min})$ and $a_{max} \equiv a(m_{max})$ be the corresponding lowest and highest induced probabilities of adoption, and $M_{a_{min}}$ and $M_{a_{max}}$ be the sets of essentially equivalent messages that induce them. We are now in a position to state our first lemma.

Lemma 5. *In any equilibrium with $a_{min} < a_{max}$ the following statements are true:*

$$\sum_{m \in M_{a_{min}}} q(m|\theta_1) = 1 \qquad \sum_{m \in M_{a_{max}}} q(m|\theta_1) = 0 \qquad \sum_{m \notin \{M_{a_{min}} \cup M_{a_{max}}\}} q(m|\theta_1) = 0 \tag{A10}$$

$$\sum_{m \in M_{a_{min}}} q(m|\theta_2) = 1 \qquad \sum_{m \in M_{a_{max}}} q(m|\theta_2) = 0 \qquad \sum_{m \notin \{M_{a_{min}} \cup M_{a_{max}}\}} q(m|\theta_2) = 0 \tag{A11}$$

$$\sum_{m \in M_{a_{min}}} q(m|\theta_3) = 0 \qquad \sum_{m \in M_{a_{max}}} q(m|\theta_3) = 1 \qquad \sum_{m \notin \{M_{a_{min}} \cup M_{a_{max}}\}} q(m|\theta_3) = 0 \tag{A12}$$

For $m \in M_{a_{min}}$, $p(\theta_1|m) = \frac{\rho_1}{\rho_1 + \rho_2}$, $p(\theta_2|m) = \frac{\rho_2}{\rho_1 + \rho_2}$, and $p(\theta_3|m) = 0$. For $m \in M_{a_{max}}$, $p(\theta_1|m) = 0$, $p(\theta_2|m) = 0$, and $p(\theta_3|m) = 1$.

In any equilibrium with $a_{min} = a_{max}$ (letting $a^* \equiv a_{min} = a_{max}$), the following statements are true:

$$\sum_{m \in M_{a^*}} q(m|\theta_i) = 1 \ \forall \ \theta_i, \qquad \sum_{m \notin M_{a^*}} q(m|\theta_i) = 0 \ \forall \ \theta_i \tag{A13}$$

For $m \in M_{a^*}$, $p(\theta_1|m) = \rho_1$, $p(\theta_2|m) = \rho_2$, and $p(\theta_3|m) = \rho_3$.

Proof. Note from (A6) that $\frac{\partial}{\partial a} \widehat{U}(a, \beta, \theta_1) < 0$, $\frac{\partial}{\partial a} \widehat{U}(a, \beta, \theta_2) < 0$ and $\frac{\partial}{\partial a} \widehat{U}(a, \beta, \theta_3) > 0$ for all $a \in [0, 1]$, since $s_1 < s_0$, $s_2 < s_0$ and $s_3 > s_0$. Hence if $a_{min} \neq a_{max}$ then in order for (A8) to be satisfied it must be the case that an agent of type θ_1 or θ_2 (i.e. that observes technology types θ_1 or θ_2) chooses messages that induce the lowest possible probability of adoption, a_{min}. Similarly, an agent who observes θ_3 will choose a message that induces the highest possible probability of adoption, a_{max}. Given these signaling rules, the updating of the principal's beliefs follow by Bayes' rule. If $a_{min} = a_{max}$ then trivially all messages sent by the agent induce the same action and hence are essentially equivalent ($M_{a_{min}} = M_{a_{max}} = M_{a^*}$). Given this, the principal does not update. $\square$

We have shown that for a given β, only two types of subgame equilibria may exist: one type in which $a_{min} \neq a_{max}$ and agent types θ_1 and θ_2 are indistinguishable and another in which the principal ignores the signal from the agent (a "babbling" type). If we consider essentially equivalent messages to be identical, then we can say that there can exist at most two equilibria in each subgame for a given β.

4

It will be convenient below to define the principal's ex-ante expected profit in a given subgame equilibrium. Given Lemma 5, we have:

$$
\begin{aligned}
\pi^*(\beta) \;=\; & \rho_1 \widehat{\pi}\left[a\left(m | m \in M_{a_{min}}\right), \beta, \theta_1\right] + \rho_2 \widehat{\pi}\left[a\left(m | m \in M_{a_{min}}\right), \beta, \theta_2\right] \\
& + \rho_3 \widehat{\pi}\left[a\left(m | m \in M_{a_{max}}\right), \beta, \theta_3\right]
\end{aligned}
\tag{A14}
$$

where $a(m)$ represents the principal's best response, given by (A9) and we may or may not have $a_{min} = a_{max}$.

A.2.2 Subgame with $\beta = \beta_0$

Now consider the particular subgame with $\beta = \beta_0$.

Lemma 6. *If $\beta = \beta_0$, there exists a perfect Bayesian subgame equilibrium with the strategies outlined in Proposition 1.*

Proof. Using the notation from Section A.2.1, the equilibrium outlined by Proposition 1 can be rewritten as follows:

1. The agent's signaling rules are given by (A10)-(A12), where $a_{min} = 0$, $a_{max} = 1$, $m_1 \in M_0$ and $m_2, m_3 \in M_1$.[2]

2. The principal's action rules are: $a(m) = 0 \; \forall \; m \in M_0$, $a(m) = 1 \; \forall \; m \in M_1$.

To prove that this is a subgame equilibrium, it suffices to show that neither agent nor principal wants to deviate. That the agent does not want to deviate follows from the fact (from (A6)) that $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_1) < 0$, $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_2) < 0$ and $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_3) > 0$ for all $a \in [0, 1]$. Now consider the principal's decision. Given Lemma 5, if the agent signals m_1 (or any other $m \in M_0$) then the condition for the principal not to deviate is:

$$
\pi_0(\beta) \geq \frac{\rho_1}{\rho_1 + \rho_2}\pi_1(\beta) + \frac{\rho_2}{\rho_1 + \rho_2}\pi_2(\beta)
$$

where the left-hand side is the profit from the existing technology and the right-hand side the expected profit to adoption. Given the definition of $Z(\cdot)$ in Lemma 4, the condition can be written $Z(\beta) \leq 0$. By Lemma 4, this condition is satisfied for $\beta = \beta_0$. If the agent signals m_2, m_3 or any other $m \in M_1$, then the condition for the principal not to deviate is:

$$
\pi_0(\beta) \leq \pi_3(\beta)
$$

which by Lemma 2 is satisfied for $\beta = \beta_0$. □

In this subgame, the principal's ex-ante expected profit (refer to (A14)) is:

$$
\begin{aligned}
\pi^*(\beta_0) \;=\; & \rho_1 \widehat{\pi}(0, \beta_0, \theta_1) + \rho_2 \widehat{\pi}(0, \beta_0, \theta_2) + \rho_3 \widehat{\pi}(1, \beta_0, \theta_3) \\
\;=\; & (\rho_1 + \rho_2)\pi_0(\beta_0) + \rho_3 \pi_3(\beta_0) \equiv \pi_{\beta_0}
\end{aligned}
\tag{A15}
$$

---

[2]Note that to streamline the exposition in the main text we limited the set of messages to have three elements, $M = \{m_1, m_2, m_3\}$. But nothing crucial hangs on this restriction. With a richer message set, the Proposition 1 equilibrium would have all messages falling into one of the following sets: M_0, all elements of which induce $a_{min} = 0$ and are essentially equivalent to m_1; M_1, all elements of which induce $a_{max} = 1$ and are essentially equivalent to m_2 and m_3; or the complement to $M_0 \cup M_1$, no element of which is used in equilibrium, as shown by Lemma 5.

A.2.3 Principal's choice of β

We now turn to the supergame where the principal selects the optimal β given the payoffs from the subgames corresponding to every possible value of β, analyzed in Subsection A.2.1 above. We can show that there is no greater payoff than $\pi^*(\beta_0)$ (from (A15)) from choosing another β in Stage 1, and hence that the principal has no incentive to deviate from β_0 in the supergame.

Lemma 7. *The principal's expected payoff in the informative equilibrium of the subgame with piece rate β_0 is strictly greater than the payoffs in the subgames for all other possible values of β.*

Proof. From Lemma 5, types θ_1 and θ_2 can never be distinguished. Therefore, the highest possible payoff to the principal from any subgame equals the payoff that the principal would obtain if she observed whether $\theta = \theta_3$ or $\theta \in \{\theta_1, \theta_2\}$ — the largest amount of information she can hope to extract from the agent.[3] Here we consider the maximal payoffs in all subgames under the assumption that the principal is able to extract this information. Let $\Theta_{1,2} = \{\theta_1, \theta_2\}$; as shorthand, we say that the technology is "type Θ_{12}" if the principal knows only that $\theta \in \Theta_{12}$. There are only four cases to consider, which may exist for different values of β.[4]

1. It is profitable for the principal to adopt type θ_3 but not type Θ_{12}, i.e.

$$\widehat{\pi}(1, \beta, \theta_3) \geq \widehat{\pi}(0, \beta, \theta_3)$$
$$\frac{\rho_1}{\rho_1 + \rho_2}\widehat{\pi}(1, \beta, \theta_1) + \frac{\rho_2}{\rho_1 + \rho_2}\widehat{\pi}(1, \beta, \theta_2) < \frac{\rho_1}{\rho_1 + \rho_2}\widehat{\pi}(0, \beta, \theta_1) + \frac{\rho_2}{\rho_1 + \rho_2}\widehat{\pi}(0, \beta, \theta_2)$$

   By Lemmas 1-3, this case holds when $\beta = \beta_0$. In this case, the principal's maximal ex-ante expected profit (refer to (A14)) is:

$$\begin{aligned}\pi^*(\beta) &= \rho_1\widehat{\pi}(0, \beta, \theta_1) + \rho_2\widehat{\pi}(0, \beta, \theta_2) + \rho_3\widehat{\pi}(1, \beta, \theta_3) \\ &= (\rho_1 + \rho_2)\pi_0(\beta) + \rho_3\pi_3(\beta)\end{aligned} \tag{A16}$$

   From the definition of $\pi_i(\cdot)$ in (2) it follows immediately that the expected payoff is maximized at $\beta^* = \beta_0 \equiv \frac{p - c_0}{2}$, i.e. $\pi^*(\beta_0) = \pi_{\beta_0} > \pi^*(\beta) \; \forall \; \beta \neq \beta_0$. where π_{β_0} was defined in (A15). Hence for all subgames that fall into this case, the principal prefers β_0 to any other β.

2. It is not profitable for the principal to adopt either type θ_3 or type Θ_{12}, i.e.

$$\widehat{\pi}(1, \beta, \theta_3) < \widehat{\pi}(0, \beta, \theta_3)$$
$$\frac{\rho_1}{\rho_1 + \rho_2}\widehat{\pi}(1, \beta, \theta_1) + \frac{\rho_2}{\rho_1 + \rho_2}\widehat{\pi}(1, \beta, \theta_2) < \frac{\rho_1}{\rho_1 + \rho_2}\widehat{\pi}(0, \beta, \theta_1) + \frac{\rho_2}{\rho_1 + \rho_2}\widehat{\pi}(0, \beta, \theta_2)$$

   In this case, the principal's ex-ante expected profit (refer to (A14)) is:

$$\pi^*(\beta) = \rho_1\widehat{\pi}(0, \beta, \theta_1) + \rho_2\widehat{\pi}(0, \beta, \theta_2) + \rho_3\widehat{\pi}(0, \beta, \theta_3) = \pi_0(\beta) \tag{A17}$$

   From (2), β_0 maximizes $\pi_0(\beta)$, i.e. $\pi_0(\beta_0) \geq \pi_0(\beta) \; \forall \; \beta$. But by Lemma 2, $\pi_3(\beta_0) > \pi_0(\beta_0)$

---

[3]This is a simple application of Blackwell's ordering, i.e. that the decision maker's payoff must be weakly higher with more information (see Blackwell (1953).)

[4]The sets of values of β for which the different cases hold depend on the values of the parameters $\hat{\hat{\beta}}_3$ and $\overline{\beta}$ defined in Lemmas 2 and 4. There are two possibilities: (1) $\overline{\beta} \geq \hat{\hat{\beta}}_3$. Here the region $(0, \hat{\beta}_3)$ corresponds to Case 2 below, $[\hat{\beta}_3, \hat{\hat{\beta}}_3]$ to Case 1, $[\hat{\hat{\beta}}_3, \overline{\beta}]$ to Case 2, and $(\overline{\beta}, \infty)$ to Case 4. (2) $\overline{\beta} < \hat{\hat{\beta}}_3$. Here the region $(0, \hat{\beta}_3)$ corresponds to Case 2 below, $[\hat{\beta}_3, \overline{\beta})$ to Case 1, $[\overline{\beta}, \hat{\hat{\beta}}_3]$ to Case 3, and $(\hat{\hat{\beta}}_3, \infty)$ to Case 4.

and hence $\pi_{\beta_0} > \pi_0(\beta_0) \geq \pi_0(\beta)$ (where π_{β_0} is from (A15)). Hence the principal prefers the subgame with β_0 to any subgame that falls under this case.

3. It is profitable for the principal to adopt both type θ_3 and type Θ_{12}, i.e.

$$\widehat{\pi}(1,\beta,\theta_3) \geq \widehat{\pi}(0,\beta,\theta_3)$$

$$\frac{\rho_1}{\rho_1+\rho_2}\widehat{\pi}(1,\beta,\theta_1) + \frac{\rho_2}{\rho_1+\rho_2}\widehat{\pi}(1,\beta,\theta_2) \geq \frac{\rho_1}{\rho_1+\rho_2}\widehat{\pi}(0,\beta,\theta_1) + \frac{\rho_2}{\rho_1+\rho_2}\widehat{\pi}(0,\beta,\theta_2)$$

In this case, the principal's ex-ante expected profit is:

$$\pi^*(\beta) = \rho_1\pi_1(\beta) + \rho_2\pi_2(\beta) + \rho_3\pi_3(\beta) = \widetilde{\pi}(\beta) \tag{A18}$$

where $\widetilde{\pi}(\cdot)$ is defined as in Section 6.2.1 above. Since $\widetilde{\beta}$ is the optimal choice if the principal bases her decision only on her priors and adopts (refer to (4)), it must be the case that $\widetilde{\pi}(\widetilde{\beta}) \geq \widetilde{\pi}(\beta)$ for all β. But by condition (5c), $\pi_0(\beta_0) > \widetilde{\pi}(\widetilde{\beta})$. As above, Lemma 2 implies $\pi_{\beta_0} > \pi_0(\beta_0)$ (where π_{β_0} is from (A15)). Hence $\pi_{\beta_0} > \pi_0(\beta_0) > \widetilde{\pi}(\widetilde{\beta}) \geq \widetilde{\pi}(\beta) \; \forall \; \beta$; the principal prefers the subgame with β_0 to any subgame that falls under this case.

4. It is not profitable for the principal to adopt type θ_3 but it is profitable for type Θ_{12},[5] i.e.

$$\widehat{\pi}(1,\beta,\theta_3) < \widehat{\pi}(0,\beta,\theta_3)$$

$$\frac{\rho_1}{\rho_1+\rho_2}\widehat{\pi}(1,\beta,\theta_1) + \frac{\rho_2}{\rho_1+\rho_2}\widehat{\pi}(1,\beta,\theta_2) \geq \frac{\rho_1}{\rho_1+\rho_2}\widehat{\pi}(0,\beta,\theta_1) + \frac{\rho_2}{\rho_1+\rho_2}\widehat{\pi}(0,\beta,\theta_2)$$

In this case, the principal's ex-ante expected profit (refer to (A14)) is:

$$\pi^*(\beta) = \rho_1\pi_1(\beta) + \rho_2\pi_2(\beta) + \rho_3\pi_0(\beta) \tag{A19}$$

Consider the function $\widetilde{\widetilde{\pi}}(\beta) = \rho_1\pi_1(\beta) + \rho_2\pi_2(\beta) + \rho_3\pi_0(\beta)$ defined over all possible values of β. (That is, $\widetilde{\widetilde{\pi}}(\cdot)$ and $\pi^*(\cdot)$ coincide for values of β that yield Case 4, but for values of β that yield the other cases $\pi^*(\cdot) \geq \widetilde{\widetilde{\pi}}(\cdot)$ since $\pi^*(\cdot)$ reflects optimal adoption decisions.) Maximizing $\widetilde{\widetilde{\pi}}(\beta)$ over β yields:

$$\widetilde{\widetilde{\beta}} = \left(\frac{\rho_1 s_1^2 + \rho_3 s_0^2}{\rho_1 s_1^2 + \rho_2 s_2^2 + \rho_3 s_0^2}\right)\beta_0 + \left(\frac{\rho_2 s_2^2}{\rho_1 s_1^2 + \rho_2 s_2^2 + \rho_3 s_0^2}\right)\beta_2$$

Because $\widetilde{\widetilde{\beta}}$ maximizes $\widetilde{\widetilde{\pi}}(\beta)$ and $\widetilde{\widetilde{\pi}}(\cdot)$ is strictly convex, $\widetilde{\widetilde{\pi}}(\widetilde{\widetilde{\beta}}) > \widetilde{\widetilde{\pi}}(\beta) \; \forall \; \beta \neq \widetilde{\widetilde{\beta}}$. Because $\widetilde{\widetilde{\beta}}$ is a weighted average of β_0 and β_2, we know $\widetilde{\widetilde{\beta}} \in (\beta_0, \beta_2)$. By Lemma 2, $\pi_3(\beta) > \pi_0(\beta)$ for all $\beta \in (\beta_0, \beta_2)$ and hence $\pi^*(\widetilde{\widetilde{\beta}}) > \widetilde{\widetilde{\pi}}(\widetilde{\widetilde{\beta}})$ in this region. Since it is profitable to adopt θ_3 for $\beta = \widetilde{\widetilde{\beta}}$, Case 1 or 3 must hold. By the argument in one or the other case, $\pi_{\beta_0} > \widetilde{\widetilde{\pi}}(\widetilde{\widetilde{\beta}})$ (where π_{β_0} is from (A15)). Hence $\pi_{\beta_0} > \widetilde{\widetilde{\pi}}(\widetilde{\widetilde{\beta}}) > \widetilde{\widetilde{\pi}}(\beta)$ for values of β for which this case holds. Once again, the principal prefers the subgame with β_0 to any subgame that falls under this case.

Considering the four cases together, we can conclude the maximum possible payoff to the principal for $\beta \neq \beta_0$ is less than π_{β_0} from (A15). $\qquad \square$

---

[5]We include this case for completeness, although no informative equilibria will exist in this case as interests are completely misaligned.

Given Lemma 7, the principal does not have an incentive to deviate from $\beta^* = \beta_0$, her chosen wage in Proposition 1. By Lemma 6, the strategies outlined in Proposition 1 form a perfect Bayesian equilibrium of the subgame with $\beta^* = \beta_0$. Hence neither player has an incentive to deviate at any stage. This completes the proof of the existence of the equilibrium described in Proposition 1.

Note that if one assumes that the most informative equilibria obtain in every subgame, then a stronger result holds: the strategies described by Proposition 1 are part of a unique perfect Bayesian equilibrium, modulo treating all "essentially equivalent" messages as the same message. This follows from Lemmas 5 and 7. Recall that Lemma 5 implies that there are at most two possible equilibria (modulo treating all "essentially equivalent" messages as the same message) in each subgame for each β. The restriction that we focus on the most informative equilibrium in each subgame implies that there is at most one equilibrium in each subgame. Since a babbling equilibrium exists in every subgame, there exists exactly one equilibrium in each subgame.[6] Lemma 7 implies that the principal prefers the subgame with $\beta = \beta_0$ to all other subgames. Hence the only equilibrium of the supergame is the one characterized by the Proposition-1 strategies on the equilibrium path.

A.3 Proof of Proposition 2

For this proposition, a shorter proof is available than for Proposition 1. In Subsection A.3.1, we consider the subgame conditional on paying G and offering β^{**} and γ^{**} and show (a) that the strategies in Proposition 2, conditional on paying G, are part of a perfect Bayesian subgame equilibrium and (b) that the equilibrium replicates the payoff to the principal if the technology type were fully revealed to the principal in Stage 2. This implies that, conditional on paying G, the principal cannot do better by choosing a subgame with a different β and γ. In Subsection A.3.2, we consider the principal's decision about whether to pay G in Stage 0 and show that the strategies outlined in the proposition form an equilibrium of the supergame.

A.3.1 Subgame with G paid, $\beta = \beta^{**}$, $\gamma = \gamma^{**}$

In this subgame, for types θ_1 and θ_3, the agent's expected utility continues to be given by (A6). As above, $\frac{\partial}{\partial a}\widehat{U}(a,\beta,\theta_1) < 0$ and $\frac{\partial}{\partial a}\widehat{U}(a,\beta,\theta_3) > 0$ for all $a \in [0,1]$, since $s_1 < s_0$ and $s_3 > s_0$. For type θ_2, expected utility is now given by:

$$\widehat{U}(a,\beta,\gamma,\theta_2) = a\left(\frac{(\beta+\gamma)^2 s_2^2}{2}\right) + (1-a)\left(\frac{\beta^2 s_0^2}{2}\right) \tag{A20}$$

Here condition (5a) implies that $\frac{\partial}{\partial a}\widehat{U}(a,\beta,\gamma,\theta_2) > 0$ for $\beta = \beta^{**}$, $\gamma = \gamma^{**}$ and hence that agent type θ_2 wants to *encourage* adoption.[7] In this subgame, a result analogous to Lemma 5 holds.[8]

---

[6]To be precise, it can be shown that there are informative equilibria only when it is profitable for the principal to adopt θ_3 and not Θ_{12} which is true for $\beta \in (\hat{\beta}_3, \hat{\hat{\beta}}_3)$ if $\overline{\beta} \geq \hat{\hat{\beta}}_3$, and $\beta \in (\hat{\beta}_3, \overline{\beta})$ if $\overline{\beta} < \hat{\hat{\beta}}_3$.

[7]To see this, note that condition (5a) implies $\pi_2(\beta_2) > \pi_0(\beta_0)$, since $\pi_2(\beta)$ is increasing for $\beta \in [\beta_0, \beta_2]$. Using (2) and (3), we have that $\frac{((\beta^{**}+\gamma^{**})s_2)^2}{2} > \frac{(\beta^{**}s_0)^2}{2}$, which in turn implies $\frac{\partial}{\partial a}\widehat{U}(a,\beta,\gamma,\theta_2) > 0$.

[8]This lemma holds in any subgame in which $\gamma > \beta\left(\frac{s_0-s_2}{s_2}\right)$ and hence $\frac{\partial}{\partial a}\widehat{U}(a,\beta,\gamma,\theta_2) > 0$.

Lemma 8. *In any equilibrium with $a_{min} < a_{max}$ the following statements are true:*

$$\sum_{m \in M_{a_{min}}} q(m|\theta_1) = 1 \qquad \sum_{m \in M_{a_{max}}} q(m|\theta_1) = 0 \qquad \sum_{m \notin \{M_{a_{min}} \cup M_{a_{max}}\}} q(m|\theta_1) = 0 \qquad \text{(A21)}$$

$$\sum_{m \in M_{a_{min}}} q(m|\theta_2) = 0 \qquad \sum_{m \in M_{a_{max}}} q(m|\theta_2) = 1 \qquad \sum_{m \notin \{M_{a_{min}} \cup M_{a_{max}}\}} q(m|\theta_2) = 0 \qquad \text{(A22)}$$

$$\sum_{m \in M_{a_{min}}} q(m|\theta_3) = 0 \qquad \sum_{m \in M_{a_{max}}} q(m|\theta_3) = 1 \qquad \sum_{m \notin \{M_{a_{min}} \cup M_{a_{max}}\}} q(m|\theta_3) = 0 \qquad \text{(A23)}$$

For $m \in M_{a_{min}}$, $p(\theta_1|m) = 1$, $p(\theta_2|m) = 0$, and $p(\theta_3|m) = 0$. For $m \in M_{a_{max}}$, $p(\theta_1|m) = 0$, $p(\theta_2|m) = \frac{\rho_2}{\rho_2 + \rho_3}$, and $p(\theta_3|m) = \frac{\rho_3}{\rho_2 + \rho_3}$.
In any equilibrium with $a_{min} = a_{max}$ (letting $a^* \equiv a_{min} = a_{max}$), the following statements are true:

$$\sum_{m \in M_{a^*}} q(m|\theta_i) = 1 \ \forall \ \theta_i, \qquad \sum_{m \notin M_{a^*}} q(m|\theta_i) = 0 \ \forall \ \theta_i \qquad \text{(A24)}$$

For $m \in M_{a^*}$, $p(\theta_1|m) = \rho_1$, $p(\theta_2|m) = \rho_2$, and $p(\theta_3|m) = \rho_3$.

Proof. Given that $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_1) < 0$, $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_2) > 0$ and $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_3) > 0$ for all $a \in [0,1]$, if $a_{min} \neq a_{max}$ then in order for (A8) to be satisfied it must be the case that an agent of type θ_1 chooses messages that induce the lowest possible probability of adoption, a_{min}, and agents of type θ_2 or θ_3 choose a message that induces the highest possible probability of adoption, a_{max}. Given these signaling rules, the updating of the principal's beliefs follow by Bayes' rule. If $a_{min} = a_{max}$ then trivially all messages sent by the agent induce the same action and hence are essentially equivalent ($M_{a_{min}} = M_{a_{max}} = M_{a^*}$). Given this, the principal does not update. $\qquad \square$

As in Lemma 5, we have shown that there exist at most two equilibria in this subgame (modulo treating equilibria that differ only in which messages are sent from sets of essentially equivalent messages as equivalent.) We can also show existence of the informative subgame equilibrium.

Lemma 9. *If G is paid, $\beta^{**} = \frac{p - c_0}{2}$ and $\gamma^{**} = \frac{c_0 - c_2}{2}$, there exists a perfect Bayesian subgame equilibrium with the strategies outlined in Proposition 2.*

Proof. The subgame equilibrium outlined by Proposition 2 (after paying G) can be rewritten as follows:

1. The agent's signaling rules are given by (A21)-(A23), where $a_{min} = 0$, $a_{max} = 1$, $m_1 \in M_0$, and $m_2, m_3 \in M_1$.[9]

2. The principal's action rules are: $a(m) = 0 \ \forall \ m \in M_0$, $a(m) = 1 \ \forall \ m \in M_1$.

To prove that this is a subgame equilibrium, it suffices to show that neither agent nor principal wants to deviate. Since $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_1) < 0$, $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_2) > 0$ and $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_3) > 0$ for all $a \in [0,1]$, the agent has no incentive to deviate. Now consider the principal's decision. Given Lemma 8, If the agent signals m_1 (or any other $m \in M_0$), the condition for the principal not to deviate is:

$$\pi_0(\beta^{**}) > \pi_1(\beta^{**})$$

---

[9]Again, limiting messages to $\{m_1, m_2, m_3\}$ in the statement of the proposition is for expositional convenience. See footnote 2.

which is satisfied for $\beta = \beta^{**} = \beta_0$ by Lemma 3. If the agent signals m_2 or m_3 (or any other $m \in M_1$) then the condition for the principal not to deviate is:

$$\pi_0(\beta_0) \leq \left(\frac{\rho_2}{\rho_2 + \rho_3}\right) \pi_2(\beta_2) + \left(\frac{\rho_3}{\rho_2 + \rho_3}\right) \pi_3(\beta_0) \tag{A25}$$

since $\beta^{**} = \beta_0$ and $\beta^{**} + \gamma^{**} = \beta_2$. Since $\pi_2(\beta)$ is increasing for $\beta \in [\beta_0, \beta_2)$, condition (5a) implies $\pi_0(\beta_0) < \pi_2(\beta_2)$. That $\pi_0(\beta_0) < \pi_3(\beta_0)$ follows directly from the fact that $s_0 < s_3$. Hence the right-hand-side of (A25) is a weighted average of two quantities greater than $\pi_0(\beta_0)$ and (A25) is satisfied. $\square$

In this subgame, the principal's ex-ante expected profit (refer to (A14)) is:

$$\begin{aligned}
\pi^{**}(\beta^{**}, \gamma^{**}) &= \rho_1 \widehat{\pi}(0, \beta_0, \theta_1) + \rho_2 \widehat{\pi}(1, \beta_2, \theta_2) + \rho_3 \widehat{\pi}(1, \beta_0, \theta_3) - G \\
&= \rho_1 \pi_0(\beta_0) + \rho_2 \pi_2(\beta_2) + \rho_3 \pi_3(\beta_0) - G
\end{aligned} \tag{A26}$$

Now compare this payoff to what would obtain in the conditional contracts case if the technology were fully revealed to the principal in Stage 2. Recalling (3), the principal would offer β_0 under the existing technology and types θ_1 and θ_3 and β_2 under type θ_2. She would adopt types θ_2 and θ_3, and not adopt type θ_1.[10] Her ex-ante expected profit would be equal to (A26). That is, when G is paid, the conditional contract with β^{**} and γ^{**} exactly replicates the payoff to the principal if she observed the technology type herself in Stage 2. The insight of Blackwell (1953), mentioned above, is that the principal cannot do better than she would do with full information. Hence conditional on paying G, no subgame can offer the principal a better payoff than the one she receives from offering $(\beta^{**}, \gamma^{**})$. Conditional on paying G, the principal has no incentive to deviate to offer a different β or γ.

A.3.2 Principal's choice of whether to pay G

We now consider the principal's choice of whether to pay G in Stage 0. Suppose $G < \rho_2(\pi_2(\beta_2) - \pi_0(\beta_0))$ (i.e. that (7) is satisfied) and the principal pays G and offers $(\beta^{**}, \gamma^{**})$. Her payoff is given by $\pi^{**}(\beta^{**}, \gamma^{**})$ in (A26) above. If she were to deviate and not pay G, the resulting subgame would identical to the interaction analyzed in Proposition 1. In this case, the maximal payoff she could obtain is π_{β_0} from (A15). If (7) holds, then $\pi^{**}(\beta^{**}, \gamma^{**}) > \pi_{\beta_0}$ and she does not have an incentive to deviate to receive the maximal payoff from not paying G. If this is true for the maximal payoff from deviating, it is also true for all other payoffs from deviating.

Similarly, suppose $G \geq \rho_2(\pi_2(\beta_2) - \pi_0(\beta_0))$ (i.e. that (7) is not satisfied). Then the principal does not pay G and offers $\beta = \beta_0 = \frac{p - c_0}{2}$. Her payoff is given π_{β_0} from (A15). If she were to deviate and pay G, the maximal payoff she could obtain is $\pi^{**}(\beta^{**}, \gamma^{**})$ in (A26). If (7) holds, then $\pi^{**}(\beta^{**}, \gamma^{**}) < \pi_{\beta_0}$ and she does not have an incentive to deviate to receive the maximal payoff from paying G. If this is true for the maximal payoff from paying G, it is also true for all other payoffs from deviating.

We have already shown that neither player has an incentive to deviate in the resulting subgames. Hence the strategies described in Proposition 2 form a perfect Bayesian equilibrium.

A.4 Theoretical Prediction for Incentive Intervention

Here we state formally and prove the claim made informally in the main text (Section 6.2.5); that a lump-sum payment offered by a third-party experimenter conditional on the technology being revealed to be type θ_2, if sufficiently large, can induce the agent to reveal truthfully and lead to

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[10]To see this, note that $\pi_0(\beta_0) > \pi_1(\beta_1)$ and $\pi_0(\beta_0) < \pi_3(\beta_0)$ from Lemmas 2-3, and $\pi_0(\beta_0) < \pi_2(\beta_2)$ from Lemma 1 and the fact that $\pi_2(\beta_2) \geq \pi_2(\beta_0)$ since β_2 is the optimal wage under type θ_2.

adoption of the type θ_2 technology. Suppose that the players have coordinated on the equilibrium described in Proposition 1 (or, equivalently, on the equilibrium in Proposition 2 where G is large and the conditional contracts are not offered.) In Stage 1, the principal offers wage contract $(\alpha^* = 0, \beta^* = \frac{p - c_0}{2})$. Now suppose that in Stage 2 a third-party experimenter, without forewarning, offers a conditional lump-sum payment, L, conditional on the marginal cost being c_2. We have the following result for the subgame that follows this intervention.

Proposition 3. *In the subgame described above, if*

$$L > \frac{(p - c_0)^2 (s_0^2 - s_2^2)}{8} \tag{A27}$$

then the following strategies are part of a perfect Bayesian subgame equilibrium.

1. *In Stage 3, the agent signals truthfully.*

2. *In Stage 4, the principal:*

   (a) *adopts if the agent signals m_2 or m_3,*

   (b) *does not adopt if the agent signals m_1.*

Proof. It again suffices to show that there is no profitable deviation for either principal or agent. Using the notation from Section A.2.1, the subgame equilibrium outlined by Proposition 3 can be rewritten as follows:

1. The agent's signaling rules are given by (A21)-(A23), where $a_{min} = 0$, $a_{max} = 1$, $m_1 \in M_0$ and $m_2, m_3 \in M_1$.

2. The principal's action rules are: $a(m) = 0\ \forall m \in M_0$, $a(m) = 1\ \forall m \in M_1$.

That the agent does not want to deviate if he is of type θ_1 or θ_3 follows from the fact (from (A6)) that $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_1) < 0$ and $\frac{\partial}{\partial a}\widehat{U}(a, \beta, \theta_3) > 0$ for all $a \in [0, 1]$. That the agent does not want to deviate if he is of type θ_2 follows from the fact that

$$\widehat{U}(a, \beta^*, L, \theta_2) = a\left(\frac{(\beta^*)^2 s_2^2}{2} + L\right) + (1 - a)\left(\frac{(\beta^*)^2 s_0^2}{2}\right) \tag{A28}$$

and (A27) implies $\frac{\partial}{\partial a}\widehat{U}(a, \beta^*, L, \theta_2) > 0$ for all $a \in [0, 1]$.

Now consider the principal's decision. If the signal is m_1, then the condition for the principal not to deviate can be written:

$$\pi_0(\beta_0) \geq \pi_1(\beta_0)$$

which is true by Lemma 3. If the signal is m_2, then the condition for the principal not to deviate can be written:

$$\pi_2(\beta_0) \geq \pi_0(\beta_0)$$

where there is no L on the left hand side since we, rather than the principal, pay the lump-sum bonus. This inequality is true by Lemma 1. If the signal is m_3, then the condition for the principal not to deviate can be written:

$$\pi_3(\beta_0) \geq \pi_0(\beta_0)$$

which is true by Lemma 2. $\qquad\square$

Figure A.1: U.S. Imports of Inflatable Soccer Balls
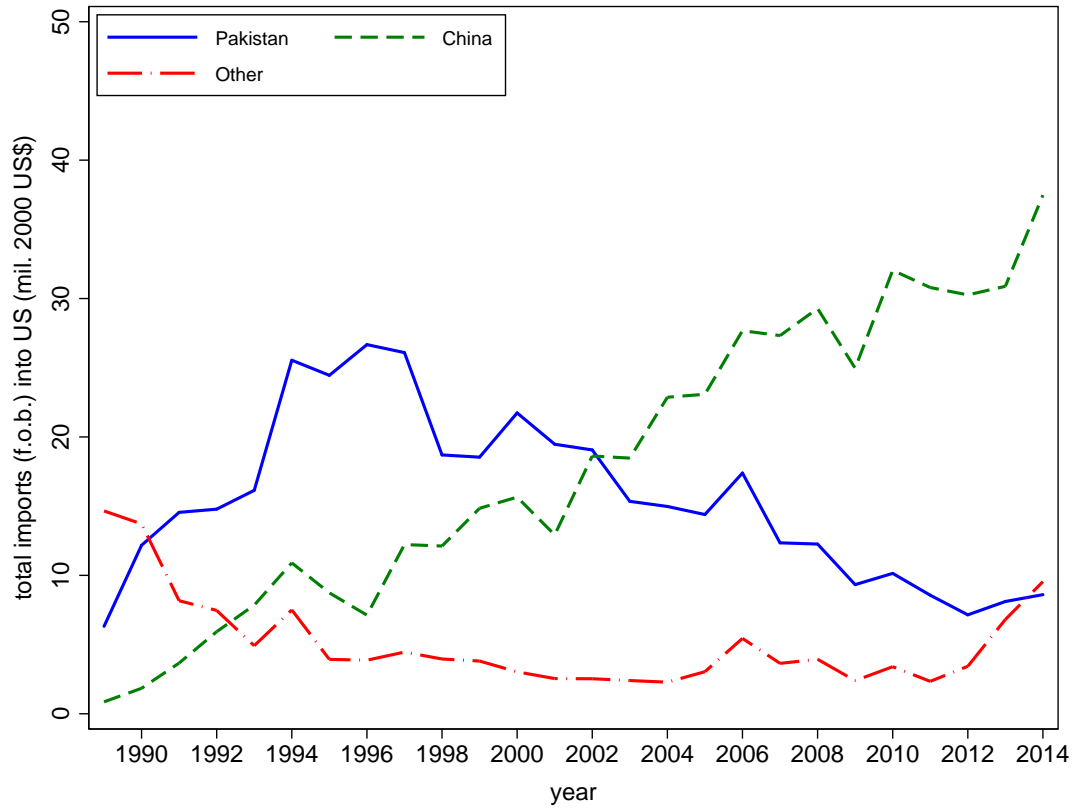
Notes: Figure shows import market shares within the United States in HS 10-digit category 9506.62.40.80 ("inflatable soccer balls"). Primary countries in "other" category are South Korea in early 1990s and Vietnam and Indonesia in 2012-2014. Source: United States International Trade Commission.

Figure A.2: Distribution of Piece Rates
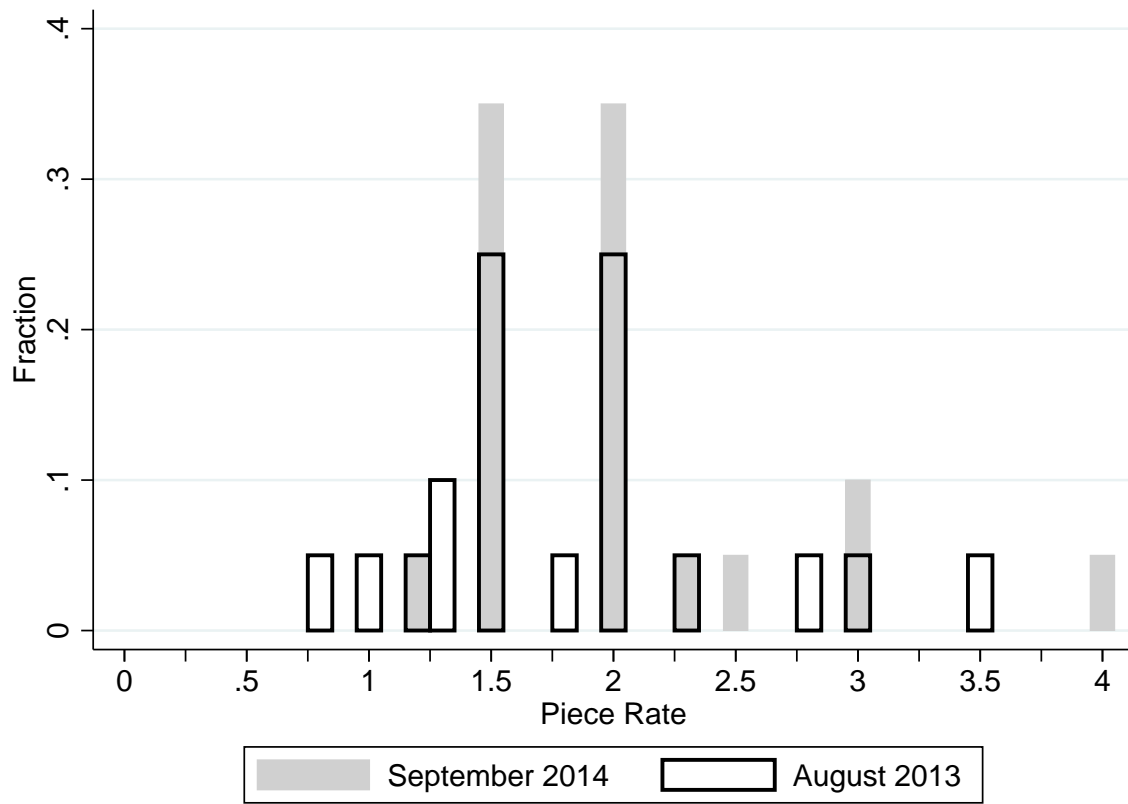
Notes: Figure displays the distribution of piece rates paid by firms using data collected in Round 7 of our survey.

Figure A.3: Effect of Incentive Treatment Under Assumption It Only Reduced Fixed Costs
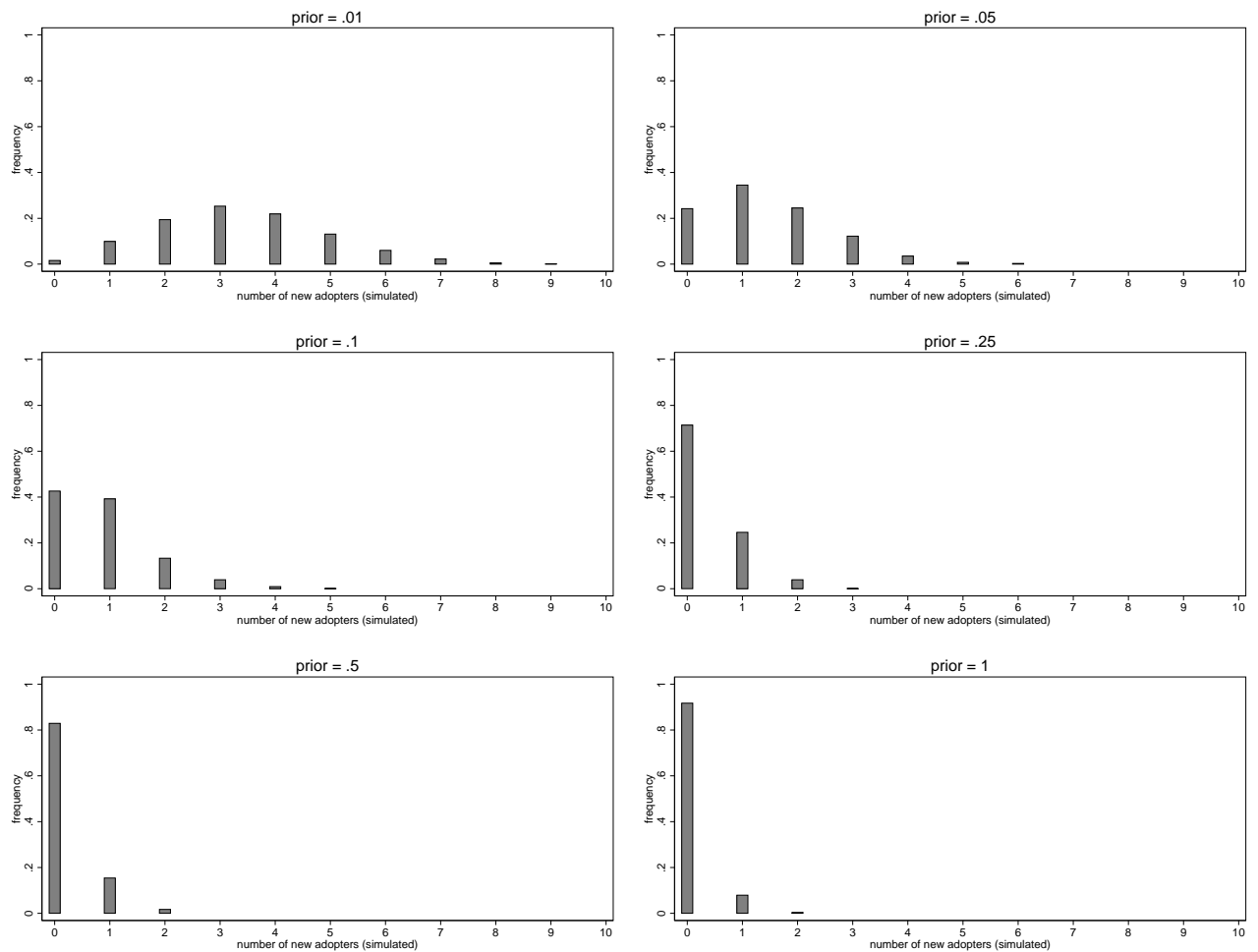
Notes: Figure displays the distribution of the number of firms from Group A predicted to respond to the incentive intervention in the short-run, using 1,000 simulation draws from a normal distribution with mean and standard deviation reported in Table 14. We use the liberal measure of adoption for this analysis. See Section 9.1 for more details.

Table A.1: Correlates of Adoption: Scale & Quality Variables (Initial-Responder Sample)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					Dep. var.: indicator for currently using offset die					
tech drop group	0.14*	0.14*								0.13*
	(0.07)	(0.07)								(0.07)
cash drop group		0.00								
		(0.02)								
log avg output/month			0.02	0.02		0.01				0.02
			(0.02)	(0.02)		(0.02)				(0.03)
log avg output*tech drop				-0.05						
				(0.05)						
share standard (of size 5)					-0.42	-0.42				-0.45*
					(0.30)	(0.31)				(0.26)
log avg price, size 5 training							-0.02			-0.09
							(0.02)			(0.07)
avg share promotional (of size 5)								-0.04		-0.06
								(0.04)		(0.07)
avg profit rate, size 5 training									0.63	0.41
									(0.68)	(0.55)
constant	0.03	0.03	-0.08	-0.17	0.44	0.33	0.16	0.08	0.02	0.78
	(0.05)	(0.05)	(0.17)	(0.14)	(0.30)	(0.40)	(0.15)	(0.06)	(0.05)	(0.53)
stratum dummies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.15	0.15	0.06	0.19	0.17	0.17	0.06	0.05	0.07	0.29
N	79	79	79	79	74	74	69	79	67	64

Notes: Table reports linear probability regressions of technology adoption, measured using the liberal definition, on firm characteristics for the initial-responder sample. Variables beginning with "avg ..." represent within-firm averages across all rounds for which responses are available. Output is measured as total balls produced per month. The "share standard (of size 5)" is the share of size 5 balls that are the standard "buckyball" design. The "avg share promotional (of size 5)" is the average share of size 5 balls that are promotional. The "avg profit rate, size 5 training" is the firm's self-reported profit rate on training balls. All regressions include stratum dummies. Significance: * 0.10, ** 0.05, *** 0.01.

Table A.2: 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)
tech drop group	0.14*									0.11
	(0.07)									(0.13)
CEO university indicator		0.05								-0.08
		(0.07)								(0.09)
CEO experience (/100)			-0.13							-1.88
			(0.12)							(1.61)
age of firm (/100)				-0.04						-0.02
				(0.08)						(0.21)
Rs/ball, head cutter					0.13					0.26
					(0.14)					(0.24)
head cutter experience (/100)						-0.03				0.38
						(0.09)				(0.86)
head cutter tenure (/100)							-0.19			0.19
							(0.23)			(0.88)
cutter raven's score								-0.03		-0.02
								(0.03)		(0.09)
avg pent/sheet, rescaled (/100)									0.55	1.29
									(0.34)	(1.36)
log avg output/month										-0.02
										(0.10)
constant	0.03	0.05	0.08	0.07	-0.15	0.00	0.03	0.05	-1.32	-3.26
	(0.05)	(0.05)	(0.07)	(0.05)	(0.18)	(0.01)	(0.03)	(0.06)	(0.82)	(3.87)
stratum dummies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
R-squared	0.15	0.06	0.05	0.05	0.10	0.12	0.12	0.10	0.08	0.49
N	79	70	77	78	74	33	32	37	70	25

Notes: Table reports linear probability regressions of technology adoption, measured using the liberal definition, on manager and cutter characteristics for the initial-responder sample. "Rs/ball, head cutter" is the rupee payment per ball to the head cutter. "cutter raven's score" is the cutter's raven's test score measured at baseline. Variables beginning with "avg ..." represent within-firm averages across all rounds for which responses are available. All regressions include stratum dummies. Significance: * 0.10, ** 0.05, *** 0.01.

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Table A.3: Wage Changes from August 2013 to September 2014

| | Panel A: Owner Responses | | |
	No Change (1)	Change (2)	Total Firms (3)
Head Cutter	10	14	24
Other Cutters	2	6	8
Head Printer	13	11	24
Other Printers	10	6	16

| | Panel B: Employee Responses | | |
	No Change (1)	Change (2)	Total Responses (3)
Head Cutters (Self-Reported)	14	3	17
Printers (Self-Reported)	13	4	17

Notes: Table reports the number of firms that make changes to wages between August 2013 and September 2014. All changes are increases. Panel A reports responses by the firm owner. Panel B reports self-reported responses by the head cutter and the printers (for some firms, we have responses from several printers). These data were collected in Round 7 of our survey.

Table A.4: Reasons for Changing Payments

	Head Cutter (1)	Other Cutters (2)	Head Printer (3)	Other Printers (4)
Because of Offset Die	1	1	0	0
New Hire	1	0	0	0
Worker Shortage	0	0	0	0
Prices were increasing	3	0	1	1
End of year change	4	2	1	1
Other	1	1	2	1

Notes: Table reports the owners' reasons for changing wages of employees between August 2013 and September 2014. These data were collected in Round 7 of our survey.

Table A.5: Why Owners Do Not Suggest Changes to Incentives

	(1)
I did not think about offering an incentive	3
Offering incentives to workers beyond their current piece rate is not common	2
I thought about offering an incentive, but the benefits of adoption were not high enough	1
If I offered an incentive to some workers, then other workers would perceive this to be unfair	3
If I offered an incentive, workers would expect additional incentives in the future for other tasks	6
Even if I had offered an incentive, the workers would not have adopted the offset die	0
Other	3
N	18

Notes: Table reports the reasons why firm owners do not offer incentives to use the offset die. The owners were asked to choose from the list of reasons reported in the table. These data were collected in Round 7 of our survey.

Table A.6: Why Head Cutters Do Not Suggest Changes to Incentives

	(1)
I did not think any changes in payment scheme were needed.	0
It is not my place to make suggestions about the payment scheme.	14
Management would be unlikely to listen to a suggestion from me about the payment scheme.	0
Suggesting would make it more likely that the firm would adopt and my income would decline.	0
Other	2
N	16

Notes: Table reports the reasons why head cutters do not suggest making changes to the payment scheme to adopt the offset die. The cutters were asked to choose from the list of reasons reported in the table. These data were collected in Round 7 of our survey.

Table A.7: Conversations about Changes to Payments

	Panel A: Owners' reports of conversations about changing payment schemes to adopt offset die		
	Head Cutter (1)	Other Cutters (2)	Head Printer (3)
Yes	1	1	1
No	21	7	21
Not Applicable	0	14	0
N	22	22	22

	Panel B: Head cutters' reports of conversations about changing payment schemes to adopt offset die		
	Owner (1)	Head Printer (2)	Other Cutters (3)
Yes	0	0	0
No	16	16	8
Not Applicable	0	0	8
N	16	16	16

Notes: Table reports the answers to the question: "Did you discuss with any of the following people that the firm's payment scheme should be changed if the new offset die is adopted?" Panel A reports responses by the owner with the person in question indicated at the top of each column. Panel B reports responses by the head cutter. "Not applicable" means that the firm did not have an employee in the indicated category. These data were collected in Round 7 of our survey.

Table A.8: Conversations about the Offset Die

	Head Cutter (1)	Other Cutters (2)	Head Printer (3)
Yes	10	6	6
No	12	2	16
Not Applicable	0	14	0
N	22	22	22

 Notes: Table reports owners' answers to the question: "Did you have a conversation with this employee about whether you should adopt the offset die?" "Not applicable" means that the firm did not have an employee in the indicated category. These data were collected in Round 7 of our survey.

Table A.9: Cutters' Die Recommendation and Adoption

	Did Not Adopt (1)	Adopted (2)
Offset die is beneficial & should be adopted	0	3
Offset die is not beneficial & should not be adopted	4	2
Not sure whether the die is beneficial or not	0	1
N	4	6

 Notes: Table reports the recommendation provided to the owner by the head cutter about the offset die. "Adopt" refers to the firms that have adopted the offset die according to the liberal definition, and "No adopt" refers to the firms that have not adopted the offset die. The total number of responses match the number of "yes" responses reported in Column 2 of Table A.8. These data were collected in Round 7 of our survey.

Table A.10: Adoption Speed of the "Back-to-Back" Pentagon Die

	Total Firms (1)
Adopted when firm was born	1
Within a Month	3
1 Month	7
3 Months	2
6 Months	1
>6 Months	0
N	14

Notes: Table reports how quickly firms adopted the two-panel "back-to-back" pentagon die after they first heard about the die. These data were collected in Round 7 of our survey.

Table A.11: Was there Resistance to Adopting the "Back-to-Back" Pentagon Die?

	Cutters (1)	Printers (2)
Yes	1	1
No	23	23
N	24	24

Notes: Table reports whether firms encountered resistance to adopting the "back-to-back" pentagon die from cutters and printers. These data were collected in Round 7 of our survey.

Table A.12: Did Payments Change after Adoption of Two-Panel "Back-to-Back" Pentagon Die?

	Total Firms (1)
Piece rate increased	1
Piece rate decreased	1
No change	19
Other type of change	3
N	24

Notes: Table reports the types of changes (if any) that firms made to payments when adopting the "back-to-back" pentagon die. These data were collected in Round 7 of our survey.