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Technological Change, Relative Worker Productivity, and Firm-Level Substitution: Evidence From the NBA

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Abstract

In this article, we examine the effect, on players, of a change in the technology for scoring points in the NBA, the introduction of the three-point line. While a naive prediction about the impact of this change suggests that it would disproportionately raise the productivity and value of guards who are more likely to shoot the ball from behind the three-point line, we show in a simple model that the strategic response of the defense leads the three-point line to increase the relative productivity of players who are more likely to shoot closer to the basket. We provide evidence that centers and forwards experienced increases in relative productivity with the introduction of the three-point line. Finally, we present evidence that the labor market in the NBA adjusted by increasing the demand for height in the NBA draft. Our results highlight the potential for strategic adjustments to affect the bias of technological change.

Keywords

basketball, NBA, productivity, technological change

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Introduction

In this article, we study the effects of an exogenously imposed change in the technology for producing points in a basketball game, the introduction (and later movement of) the three-point line in the National Basketball Association (NBA). Thus, this article contributes to a growing literature addressing how the bias of technological change toward selective occupation or skill groups causes changes in the relative value and use of those groups by firms. Of course, the type of technical change we examine is different in some respects from the canonical case referenced by most labor economists, in that it is neither capital-embodied nor easily represented in an analytical production function. Nevertheless, this environment has several features that make it desirable for analysis. First, the technological change is externally imposed and is not dependent on the relative skill mix of teams or an endogenous adoption decision. Second, the number of market firms and employment within those firms is fixed, reducing the margins affected by the technical change. Further, the possible firm-level effects on the organization of work and other hierarchical management issues such as those raised in Bresnahan, Brynjolfsson and Hitt (2002) can be ignored in this context. Finally, there are easily available data to measure labor productivity and the responses by firms.

This basketball context is also of interest because it shows how technological shifts may change the relative productivity of certain groups through altering the optimal equilibrium strategies of firms rather than multiplicatively modifying per unit output. Indeed, we show that the group whose marginal point potential is increased by the three-point line is precisely the group that becomes relatively less productive once optimal equilibrium strategies are taken into account. We then analyze how this change in relative productivity affects the relative value of different player types in the NBA draft.

The remainder of this article is organized into the following sections: The second section provides a brief introductory background on the effects of technical change in the labor economics literature and the institutional details of the NBA's introduction of a three-point line. The third section introduces a simple model, similar in nature to the penalty kick model used by Chiappori, Levitt, and Groseclose (2002), to illustrate the mechanism by which the introduction of the three-point line leads to a modification of equilibrium strategies in a way that increases the relative productivity of an unintuitive positional group of players (our version of occupation). This model also makes a number of predictions about the responses of firms in relative uses of the different positional groups. The fourth section introduces the data and tests these simple predictions, showing that they are largely verified. The fourth section also looks at the further empirical effects of the relative productivity changes on the value of the affected player groups. The fifth section concludes.

Background

Technical Change and Skill or Occupational Bias

A large strand of the labor economics literature of the past generation has been devoted to investigating the effects of technological change on relative worker productivity and the resulting responses of firms to these changes. While much of this work has been dominated by the skill biased technical change story that arose to explain changes in the college wage premium and the stretching of the observed wage distribution beginning in the late 1970s (Acemoglu 2002a; Autor, Katz, & Krueger, 1998; Katz & Murphy, 1992; etc.), there is also an interest in understanding firm-level employment adjustments to technology in a more general sense.

Despite a large theoretical literature on the effects of skill biased technical change on firm production, input use and relative worker wages (see summaries in Hornstein, Krusell, & Violante, 2005; Katz & Autor, 1999); empirical examinations of the response of skill demand and wages to these changes have largely been limited to aggregate economy or industry level analyses. There are numerous reasons for this; however, the primary barriers to a convincing identification of firm-level effects come from the endogenous nature of technological change adoption (Acemoglu, 1998, Acemoglu, 2002b) and difficulty in accounting for a wide variety of margins available for firm adjustment.

Despite these barriers, the literature has produced some widely accepted empirical evidence on the effect of technical change on the U.S. economy's relative use of input classes. Among these consistent findings is that technical change in recent decades has been accompanied by a resulting skill upgrading both within industries (Autor et al., 1998; Berman, Bound, & Griliches, 1994; Berman, Bound, & Machin, 1998) and establishments (Bernard & Jensen, 1997; Dunne, Haltiwanger, & Troske, 1996). These results are helpful in explaining the rise of the educational (college) wage premium in the face of a relative increase in labor force education. Additionally, these results are often taken as evidence that capital-embodied information technology changes were in fact skill (or more precisely, education) biased.

A more recent version of the capital-skill complementarity story has emphasized the greater importance of occupation relative to education, as the former is more closely linked to a specific set of skills, whether learned or inherent, which might be rendered more (or less) in demand due to technical change. Indeed, the work of Autor, Levy, and Murnane (2003) and Autor, Katz and Kearney (2006, 2008) provide a clear basis for understanding why some occupations might see a relative benefit/decline due to information technology and provide industry-level evidence of change in the relative productivity of various occupations. While this Occupation Biased Technical Change theory is clearly key in explaining overall labor market events of the past generation, there is some question as to how predictive it is regarding the effects of future, potentially different, varieties of technical change on firm-level behavior. Past episodes of technical change have often had exactly the opposite kind of relative bias (Goldin & Katz, 1998) and have been embodied in different forms (Atkeson & Kehoe, 2007).

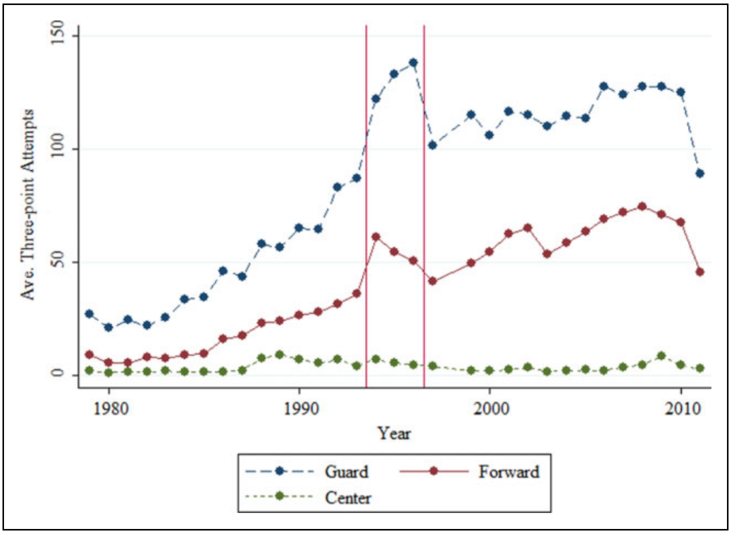

Figure 1. Average seasonal three-point attempts by position.

Background on the NBA Three-Point Line

We now turn to a brief discussion of the history of the three-point line in the NBA. Prior to the 1979-1980 NBA season, all successful baskets were worth a uniform two points. The idea that a shot made far from the basket should be given an additional point had been floated decades before and had even been used experimentally by some colleges in the post–World War II period. However, the three-point line only received widespread attention after its adoption by a rival professional basketball league, the American Basketball Association, upon its inception in 1967. Though that league folded in 1976 with its four surviving teams (of an original 11) agreeing to join the NBA, it created a popular perception that the three-point line added excitement to the game and led to the NBA adoption. The initial three-point line consisted of two side segments 22 feet from the basket extending to the foul line, joined to an arc segment 23 feet and 9 inches from the basket.

This rule change, increasing the point value of certain shot attempts, can be seen as a clear innovation in the technology for scoring points in an NBA game. However, like many changes to production technologies, it is unlikely to equally increase the productivity of all a firm's workers. Figure 1 shows the evolution of three pointers taken in the NBA from the rule's inception, by player position. The patterns in the figure are what a casual observer of the game of basketball might expect. The most three pointers are taken by players that play guard, an offensive position relatively far from the basket followed by forwards who offensively play somewhat closer to the basket. Centers, the players who play closest to the basket, take relatively few three-point shots. While this diagram might initially lead us to suspect that the introduction of the three-point line favors the relative productivity of guards, we show in the next section that it actually will have the opposite effect, increasing the relative scoring productivity of players positioned near the basket. In the fourth section, we provide empirical evidence for this potentially counterintuitive hypothesis.

Moreover, the introduction of the three-point line is not the only innovation in the point scoring rules during this era. With the stated desire to increase scoring, the NBA shortened the distance of the three-point line's arc segment to make the line a uniform 22 feet from the basket starting in the 1994-1995 season. This change lasted for 3 years and can be seen in Figure 1 as the period bracketed by the vertical lines. This creates another potential source in variability of positional production that we will use in our analysis.

The three-point shot has been used in past research by McCormick and Clement (1992) to evaluate managerial efficiency using data from the 1980-1981 through 1986-1987 NBA seasons. They note that coaches can make decisions that shift the fraction of shots that occur from behind that three-point line. Effective managers will attempt to equalize the marginal rates of return across the two types of shots. They find that this measure of efficiency differs greatly between coaches, that coaches who are more efficient along this measure achieve more wins, and that some coaches become better along this measure of efficiency. In the model that follows in the next section, we implicitly assume that coaches are optimally allocating shots across the two types to maximize point production. The type of managerial inefficiencies that McCormick and Clement identify in their article will introduce a bit of noise into our empirical work that will reduce the precision of our estimates.

Theoretical Framework

Setup

We now introduce an extremely simple and highly stylized model to illustrate the mechanism through which the introduction of a three-point line might be expected to influence the relative productivity of basketball positional groups in a particular way. This model takes the form of a two-player simultaneous move game, which we will call 2ball, with one player designated the offense and the other the defense.

Each player has two pieces in the game, which for the offensive player are designated close (C) and far (F), due to their fixed positions on the game field relative to some object. The essential element of the game is the attempt (intuitively this may be thought of as trying to hit the object with a thrown ball), which may be made by one of the pieces. If successful, an attempt from the C piece earns the offensive player m points and a successful attempt by the F piece earns n points. The move for the offensive player is a choice of which piece, C or F, will take an attempt.

The defensive player also has two pieces, and his move reflects a positional choice. He may assign his pieces to each guard one of the offensive pieces, or he may

Offense	Defense	
	1	2
C	$m\pi_1^C, -m\pi_2^C$	$m\pi_2^C, -m\pi_2^C$
F	$n\pi_1^F, -n\pi_2^F$	$n\pi_1^F, -n\pi_2^F$

Figure 2. The normal form game of 2ball.

choose to assign both of them to defend the Close piece. We will assume subsequently that the latter will reduce the Close piece's probability of completing an attempt. Thus, we can label possible defensive moves by the number of pieces used to guard the offensive C piece as $\{1,2\}$. In the former case, the other piece is implicitly used to guard the F piece.

The probabilities of a successful attempt are strategy dependent as explained subsequently and are common knowledge to both players. The offensive player is a risk neutral point maximizer and the defensive player a risk neutral point minimizer, thus the defensive player's effective payoffs to a completed attempt, by F or C, are $-n$ and $-m$, respectively.

To complete the game, we introduce the probability that an attempt is successful, which we represent as π_d^p where the superscript p reflects the offensive piece making the attempt (C or F) and the subscript d reflects the number of defending pieces assigned to the C piece. While these probabilities could be extended to make them match specific in the manner of Chiappori et al. (2002), here we assume that they are inherent to the offensive piece. The normal form payoff matrix to this game is shown in Figure 2.

Assumptions

We now make some assumptions that take the form of restrictions on the relative values of the attempt probabilities in the game. Some of these restrictions are motivated by empirical regularities observed in the game of basketball.

$$\pi_1^C > \pi_1^F, \tag{1}$$

$$\pi_1^C > \pi_2^C, \quad \pi_1^F < \pi_2^F, \quad \pi_2^C < \pi_2^F, \tag{2}$$

$$\pi_1^C - \pi_2^C > \pi_2^F - \pi_1^F. \tag{3}$$

Recall that the subscript refers to the number of defenders assigned to the C piece. Thus, the first assumption requires that an attempt from a Close piece has a higher probability of success than an attempt from the Far piece given an equal number of defenders. This incorporates the intuitive idea that distance matters negatively in attempts. The second assumption is that the probabilities of a successful attempt for either offensive piece are decreasing in the number of defenders assigned to that piece and that an uncovered far attempt has a higher probability of success than a covered close one. This incorporates the intuitive idea that defenders matter. The third, and final, assumption concerns the relative value of defense, meaning that a marginal defending piece causes a greater reduction in probability of success for a Close piece than a Far piece. Again, this reflects the empirical observation that basketball teams regularly leave perimeter players unguarded in order to double-team inside players. More importantly, we almost never see the opposite pattern of leaving interior players unguarded to double team outside players, suggesting our assumed ordering of marginal effects.

Equilibrium and Initial properties

While the finite nature of the game guarantees the existence of a Nash equilibrium, it is clear from the payoff matrix that no such equilibrium exists in pure strategies. The defense always prefers to have the marginal defender guard the attempting offensive piece, while the offense prefers to have the Close piece attempt when defense is 1, but the Far piece attempt when the defender chooses 2. In fact, the game is fundamentally of the zero-sum "Matching Pennies" variety and the unique mixed strategy equilibrium can be solved for by equating payoffs across the pure strategies conditional on the opponent's randomization.

If we allow p to define the offensive mixed strategy and constitute the probability the offense will choose the C piece for the attempt and allow q to be the corresponding probability, the defense chooses 1 in its mixed strategy. Then the equilibrium conditions will be as follows:

$$p* = \frac{n\left(\pi_2^F - \pi_1^F\right)}{n\left(\pi_2^F - \pi_1^F\right) + m\left(\pi_1^C - \pi_2^C\right)},$$
$$q* = \frac{n\pi_2^F - m\pi_2^C}{n\left(\pi_2^F - \pi_1^F\right) + m\left(\pi_1^C - \pi_2^C\right)}.$$

Initially, if we further suppose that the number of points for a successful attempt is equal across pieces, that is $n = m$, then Assumption 3 implies that the proportion of C attempts in equilibrium $p*$ will be less than one half. In contrast, the defensive mixed strategy will depend on the unspecified relative size of $\pi_2^F - \pi_2^C$ versus $\pi_1^C - \pi_1^F$. Furthermore, if we allow this game to be repeated a large number of times, we would also observe certain equilibrium output characteristics, most notably the fraction of attempts successful for each piece would be:

$$C_{\text{success}} = q\left(\pi_1^C\right) + (1-q)\left(\pi_2^C\right),$$
$$F_{\text{success}} = q\left(\pi_1^F\right) + (1-q)\left(\pi_2^F\right).$$

Other potentially interesting features of this equilibrium concern the relationship between the productivity of the pieces and equilibrium mixing of strategies. For example, decisions about the fraction of attempts given to the Close piece are invariant to an additive change in ability by either offensive piece. That is, changes to the attempt probabilities for a piece that involve an additive factor for all defensive coverage possibilities are differenced out in determining p^*. This is not true however for determination of the optimal defensive mix, which calls for the defensive player to increase the probability of allocating the marginal defender to the piece that experiences either additive or multiplicative increases in attempt success probabilities. This also creates interesting potential complementarities between pieces, as exogenously increasing the quality or success rate of a Far attempt by an additive amount (for all defensive scenarios), will increase the C_{success} rate through raising q and vice versa.

Changes to Relative Productivity

Although this simple game is highly stylized, its important predictions come when we allow a rule change to increase the nominal productivity of an F attempt. Suppose now that we increase n so that $n > m$. The following predictions emerge directly from our assumptions.

$$\frac{\delta p^*}{\delta n} > 0,$$

$$\frac{\delta q^*}{\delta n} > 0,$$

$$\frac{\delta C_{\text{success}}}{\delta n} > 0,$$

$$\frac{\delta F_{\text{success}}}{\delta n} < 0.$$

These results are the key to understanding our predictions for how the introduction of a three-point line affects the relative productivity of positional groups in the NBA. Although an increase in the value of a successful attempt by the Far piece might be expected to increase the relative productivity of that piece, the model predicts that exactly the opposite will likely occur once equilibrium strategic behavior is accounted for. The mechanism by which this occurs is easily seen in predictions 1 and 2. The equilibrium defensive strategy responds to the rule change by increasing q, the fraction of the time a defensive piece is sent to guard F. Thus, although the attempts are worth more points, the success percentage for F is lower and the productivity change, as measured by points per attempt for F, is ambiguously signed in its change.

On the other hand, the Close piece will have a higher success rate for those attempts making it unambiguously more productive than under an equal point regime and very likely relatively more productive. Furthermore, the equilibrium p increases, meaning that the F player gets fewer attempts. This last point captures the logical substitution response of firms to the change in relative productivity. Since the Close piece is relatively more productive per attempt, we would expect to see it get more attempts.

Despite the stylized nature of the model, we expect the key mechanism to carry over into the analysis of actual basketball results. That is, we expect that the shifting defensive strategy in response to the introduction of the three-point line will lead to greater relative productivity for offensive players that play close to the basket (Centers) and few, if any, changes for players far from the basket (Guards). Observers of the NBA suggested that this defensive strategy shift actually occurred. Hubie Brown, two-time NBA coach of the year remarked about the change, "You have to tell your players to remember who the shooters are, and when those guys are 25 feet from the basket ... guard them. Don't give them the 25-footer, which is something players had been conditioned to do all their lives" (Pluto, 1990).

It is more difficult to operationalize the 1994 shortening of the three-point line in this model, as it does not explicitly change the value of a particular attempt, but rather affects the underlying attempt probabilities for the Far piece. If this is modeled as a common multiplicative increase to all π_d^F, then it will act on equilibrium strategies in the same manner as an increase in n, the point value for a successful far attempt. However, if the increase is a common element added to both probabilities, it will only affect the defensive equilibrium strategy and hence equilibrium success rates, but not the offensive attempt mix probability across pieces.

Testing Model Predictions

Data

We use data from http://www.basketballreference.com to provide information on each player's height, position, draft year, and draft number as well as annual performance statistics (i.e., points, attempted shots, etc.). Table 1 provides the summary statistics for productivity and related statistics, separated into two time periods. The first period covers the 1974-1975 to 1983-1984 seasons, which includes the 5 years before and 5 years after the introduction of the three-point line in the NBA. The second time period includes the 1990-1991 to 1996-1997 seasons and includes the 3 years before and the 3 years after the NBA shortened the distance of the three-point line. Our two primary measures of player productivity are the completion rate (shots made divided by shots attempted) and points per attempted shot. The second measure adjusts for the fact that the introduction of the three-point line allowed some shots to be more valuable than others. In Table 1, we also include measures of player performance separately for three-point shots, field goals, and the number of minutes and games played.

Table 1. Descriptive Statistics.

	1974-1975 to 1983-1984		1990-1991 to 1996-1997	
	Before	After	Before	After
Points/Attempt	0.934	0.957	0.900	0.848
Completion rate	0.467	0.481	0.462	0.450
Height (feet)	6.511	6.548	6.558	6.567
Points/Game	12.79	12.76	12.50	12.075
Three-Point attempts/Game		0.260	1.005	1.941
Field goal attempts/Game	10.92	10.32	10.18	9.683
Three-Point percentage		0.173	0.232	0.292
Field goal percentage	0.467	0.486	0.472	0.462
N	1,483	1,685	1,705	1,430

Note. The first two columns include the 10 seasons that surround the introduction of the three-point line in the National Basketball Association (NBA). The last two columns include the seven seasons that surround the year in which the three-point line was shortened. The unit of observation is the player-year. All observations are weighted by minutes played.

Relative Productivity and the Introduction of the Three-Point Line

Table 2 presents some initial tests of the model predictions regarding the effects of introducing a three-point line. We use average statistics by position[1] for each team-year and show how they change from the 5 years preceding the inception of the three-point line to the 5 years following its introduction. We also show the reported differences in percentage-change terms.

The results in Table 2 largely confirm the initial predictions of the model. When considering centers, the players whose offensive position is traditionally closest to the basket, the data show that the adoption of the three-point line increased their productivity (points per attempt). Furthermore, forwards, who can play close to the net and far away from the net, experienced a greater productivity increase than the centers but not enough to erase the preexisting productivity differential (we discuss the difficulties involved with traditional measures of player position in the Measuring positioning subsection). Nevertheless, these productivity increases were relatively large, with centers experiencing about 50% of a standard deviation increase in points per attempt and their completion rate and forwards experiencing about 60% of a standard deviation increase in points per attempt and their completion rate. Finally, guards, who play farthest from the basket, saw their absolute productivity in points per attempt decrease. Not only did guards' absolute productivity fall, but they also saw even greater decreases in their relative productivity.

The table also shows that the model predictions about the distribution of shot attempts by position are consistent with what is observed in the data. Prior to the adoption of the three-point line, outside players took the majority of attempts ($p < .05$). However, with the adoption of the three-point line, teams respond to the

Table 2. Change in Attempts and Productivity by Position When the Three-Point Line Was Introduced.

	Pre	Post	Δ/σ (%)
Centers			
Fraction of team attempts	0.179	0.183	3.6
Points per attempt	0.970	1.00	47.7
Completion rate	0.485	0.502	50.0
Forwards			
Fraction of team attempts	0.397	0.393	−3.3
Points per attempt	0.935	0.977	59.1
Completion rate	0.468	0.490	65.3
Guards			
Fraction of team attempts	0.424	0.424	−0.2
Points per attempt	0.921	0.911	−12.9
Completion rate	0.460	0.461	4.0

Note. The unit of observation of is the team-year average at each position for the 1974-1975 to 1983-1984 seasons ($N = 645$). The standard deviations (σ) for fraction of team attempts, points per attempt, and completion rate are calculated across all observations in this sample and are 0.126, 0.072, and 0.035, respectively.

greater relative productivity of offensive players close to the basket (i.e., centers) by increasing their attempts at the expense of the forwards. This can be seen as evidence of firm-level substitution into the relatively more productive players.

Although these descriptive tables give a valuable picture of average changes on a team level, we wish to look more deeply at how the introduction of the three-point line affects the relative productivity of individual players, according to their position group. Thus, we next take player-season level data for the 1974-1975 to 1983-1984 seasons and analyze the effects of three-point introduction in a regression framework of the following form:

$$\text{Output}_{i,g,t,y} = \alpha\, X_{i,g,t,y} + \beta\ \text{Position}_{i,t,y} + \delta\ \text{Adopted}_t + \gamma\ \text{Position}_{i,t,y} \times \text{Adopted}_t + \varepsilon_{i,g,t,y},$$

where output is a measure of player productivity, X is a set of controls including player experience and team fixed effects, and Position and Adopted are dummy variables for a player's position group and a year after the three-point line is adopted, respectively. Note that this formulation does not contain a traditional control group that is untreated by the introduction of the three-point line. Rather, the coefficient β measures the productivity change for a position group relative to its previous performance, in effect assuming that it would have persisted in the absence of three-point adoption. Given this assumption, the interaction term coefficient γ, which we are accustomed to interpreting as a difference-in-differences effect, instead measures the relative changes in productivity between the identified position groups and other position groups that is due to the adoption of the three-point line. It is important to emphasize that the interpretation of this coefficient is as a relative (rather than

Table 3. Effects of Three-Point Line on Relative Productivity by Position.

	Introduce		Shorten	
	Points per Attempt (1)	Completion Rate (2)	Points per Attempt (3)	Completion Rate (4)
After change	−0.003 [0.009]	0.004 [0.005]	−0.072** [0.011]	−0.017** [0.005]
Forward	0.020* [0.009]	0.010* [0.005]	0.092** [0.010]	0.034** [0.005]
Center	0.046** [0.012]	0.023** [0.006]	0.123** [0.013]	0.044** [0.007]
After × Forward	0.050** [0.013]	0.021** [0.006]	0.028 [0.015]	0.002 [0.008]
After × Center	0.054** [0.016]	0.022** [0.008]	0.052** [0.020]	0.009 [0.010]
N	3,161	3,161	3,118	3,118

Note. Columns 1–2 include player-year observations from the 1974-1975 to 1983-1984 seasons. Columns 3–4 include player-year observations from the 1990-1991 to 1996-1997 seasons. The "after" variable indicates whether the observation occurred after the introduction of the three-point line (1979/1980 season) in the first two columns or after the shortening of the three-point line (1994/1995 season) in the latter two columns. All regressions contain team fixed effects.
** and * indicate statistical significance at the 1% and 5% levels, respectively.

absolute) productivity change; however, it is precisely changes in relative productivity that interest us in this article.

As available data emphasize the attempt-based nature of the game, we have chosen points per attempt and the fraction of successful attempts as our primary output measures. We use guards as the omitted position group because the three-point line is in their primary offensive area of the court.

The results of these regressions are found in Table 3. The first two columns show the effects of the introduction of the NBA three-point line on the relative productivity of centers and forwards. The results suggest that forwards and centers had a higher number of points per attempt and completion percentage than guards even before the three-point line was introduced. This likely reflects features in the game of basketball, which is not truly a simultaneous move game, which are not captured by our model. For instance, not all attempts to double team an inside offensive player work, due to incorrect timing or positioning. Additionally, the offensive player retains the option to forgo an inside shot and pass to a teammate. However, the central lesson of the model, that increased defensive attention to outside players will make inside players relatively more productive, is confirmed in the rest of the table. Looking further down the columns, we find that after the change in scoring rules, center and forward productivity increased even further, relative to guards, with relative points per attempt increasing by 0.05 for forwards and slightly more for centers.

Effects of Shortening the Three-Point Line

As we discussed in the Background section, the NBA three-point line has not always had the same form. In particular, the line was shortened for three seasons beginning in 1994-1995. We have also briefly mentioned that the predictions of the model are less clear as to what effect shortening the three-point line will have on the relative productivity of different position groups. Thus, we seek empirical evidence. In columns 3–4 of Table 3, we repeat the previous columns' empirical exercise using data from 1990-1991 to 1996-1997 seasons. While other variables remain as previously defined, the post-dummy now is set equal to one for the last 3 years of this window, when the three-point line was shortened.

The results suggest this change had productivity effects that are similar to those created by the introduction of the three-point scoring technology. The interaction terms suggest that a statistically significant increase in center productivity, relative to guards, of about 0.05 points per attempt occurred following the shortening of the three-point line. Again, our simple model suggests a likely mechanism by which this relative decline can occur for guards that would seem to be benefited by the technology change. The optimum strategy of the defenders shifts to apply more defensive pressure, on average, to guards and less to the interior players. In equilibrium, this defensive shift leads to larger productivity losses than the corresponding gains from long shots counting for more points.

Measuring Positioning

One particular concern in the foregoing analysis is the possible equivocation on what basketball positions mean. Although guards do tend to play farther from the basket than forwards or centers on average, position groups are self-defined, often in ways that reflect defensive as well as offensive positioning. Thus, many taller guards score from post moves or layups while some forwards are more likely to take a large number of shots far from the basket. It follows that the listed roster position might be a noisy measure of the fundamental object of interest, which is shot attempt distance from the basket when on offense.

We therefore consider another possible attribute that may better capture that positioning: player height. Height is objectively measured and can be expected to negatively correlate with distance from the basket on average. In essence, if the three-point line pushes defenses farther from the basket, we expect the greatest relative productivity benefit to accrue to players that can play nearer to the basket (i.e., the taller ones). In this way of viewing the problem, position becomes merely an imperfect proxy for an inherent attribute that is advantaged by technical change, much as educational status and occupation are merely measurable proxies for the actual skill of employees that is advantaged by skill-biased technical change.

The evidence for this conjecture can be found in Table 4. The table repeats the analyses of Table 3, using data from the same seasons and examining productivity changes due to the adoption, and later, shortening of the three-point line. In this table, however, the dummies for position group have been replaced by a variable that measures a player's height (in feet) and the interaction term now tells us the relative

Table 4. Effects of Three-Point Line on Relative Productivity by Height.

	Introduce		Shorten	
	Points per Attempt (1)	Completion Rate (2)	Points per Attempt (3)	Completion Rate (4)
After change	0.027** [0.006]	0.016** [0.003]	−0.055** [0.007]	−0.016** [0.003]
Height	0.064** [0.016]	0.032** [0.008]	0.130** [0.015]	0.044** [0.007]
After × Height	0.079** [0.021]	0.033** [0.010]	0.075** [0.021]	0.019 [0.011]
N	3,161	3,161	3,118	3,118

Note. Columns 1–2 include player-year observations from the 1974-1975 to 1983-1984 seasons. Columns 3–4 include player-year observations from the 1990-1991 to 1996-1997 seasons. Height is measured in feet and centered on the sample mean (6.5 feet). All regressions contain team fixed effects.
** and * indicate statistical significance at the 1% and 5% levels, respectively.

change in productivity for taller players after the three-point line changes. We also center our height measure at the sample mean (6.5 feet), so that the coefficient on the "after change" variable represents the change in productivity that accompanied each rule change for a player of average height.

The results in Table 4 indicate that the introduction of the three-point line increased the productivity of players of average height, increasing their points per attempt by 0.03 and their completion rate by 1.6%. However, the change in productivity was even larger for taller players, with an extra 6 inches of height producing a change in productivity that was more than double that for an average-height player. We also find that shortening the three-point line provided a larger advantage to taller players in terms of points per attempt but smaller and insignificant effects in terms of the completion rate.

These results suggest that the change in scoring technology represented by the three-point shot led to a relative shift in the productivity of players according to their average playing distance from the basket, consistent with the predictions of our model predictions. In the next section, we will look at how this change in relative productivity changes the return to height, making taller players more valuable to a team and increasing the demand for height in the NBA draft.

The Returns to Relative Productivity Changes

The results from the previous section suggest that the introduction, and later, shortening of the three-point line in the NBA led to a relative increase in the productivity of taller players. We now examine whether this relative change in productivity led to a change in the firm-level demand for height, by looking at the NBA draft. We first take the average height of players drafted at each

Table 5. Effects of Three-Point Line on Relative Draft Pick.

	Introduce		Shorten	
	Height		Height	
Post	0.070** [0.021]	0.068** [0.021]	0.034 [0.0405]	0.039 [0.0402]
Controls	Pick fixed effects	Pick and pick2	Pick fixed effects	Pick and pick2
N	646	646	264	264

Note. Each column represents a different regression. The dependent variable in each regression is player height. In columns 1–2, the sample includes player-year observations from the 1970-1989 seasons. Columns 3–4 alter the time frame to include the 1990-1991 to 1996-1997 seasons. After indicates the introduction of the three-point line (1979 season) in the first two columns and the shortening of the three-point line (1994 season) in the latter two columns. Controls indicate the type of controls used in each regression: Pick and pick^2 indicate the regression controls for the draft pick position and its square; Pick Fixed Effects indicate the regression uses fixed effects based on draft pick. Standard errors are shown in brackets and *t*-statistics are shown in parentheses.
** and * indicate statistical significance at the 1% and 5% levels, respectively.

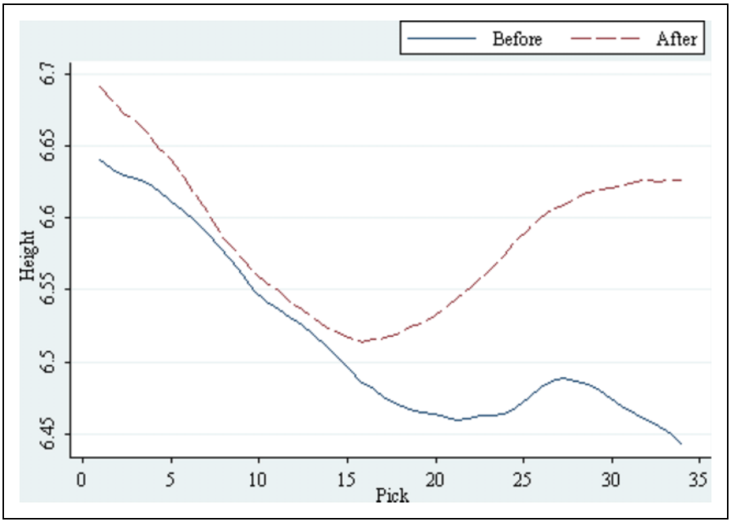

Figure 3. Average height by draft pick before and after the introduction of the three-point line. *Note.* This figure is based on data from the 1970-1989 seasons. After represents seasons after the introduction of the three-point line in 1979. The figure is produced by applying a local kernel smoother to average height by draft position within the relevant time period, using an Epanechnikov kernel and bandwidth equal to 3.

draft position for a period of 5 years before and 5 years after the introduction of the three-point line, and apply a local kernel smoother, using an Epanechnikov kernel and a bandwidth equal to 3. The results can be seen in Figure 3. It shows that after the introduction of the three-point line, there is an increase in average

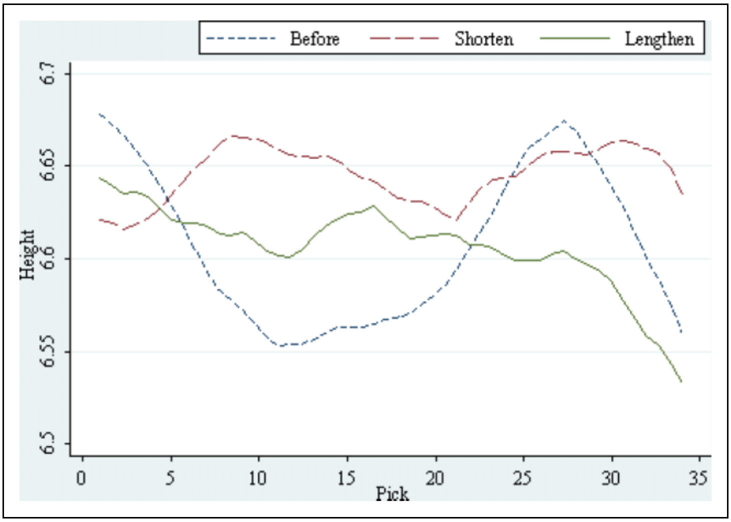

Figure 4. Average height by draft pick before and after the shortening of the three-point line and after the return to the original length. *Note.* This figure is based on data from the 1990-2000 seasons. Shorten represents seasons after the 1994 shortening of the three-point line in the NBA, but before the re-lengthening of the line. Lengthen represents seasons after the 1996 return to the original length. The figure is produced by applying a local kernel smoother to average height by draft position within the relevant time period, using an Epanechnikov kernel and bandwidth equal to 3.

player height at every draft position, though the largest change is for players drafted after the first 20 picks.

To better quantify the difference between the average heights of draftees after the three-point line innovations, we regress the height, in feet, of drafted players on a dummy variable for whether the season occurred after the rule change and a set of draft position fixed effects (see Table 5). Some specifications also add a quadratic term in draft position. We find that the introduction of the three-point line in the NBA led to a statistically significant increase in the height of players chosen in the NBA draft (an increase of about 0.07 feet on average). The shortening of the three-point line also resulted in an increase in the average height, though this change was smaller and not statistically significant. Note however, that we have a much smaller sample size in the latter two columns, because the shortened three-point line only lasted for three seasons.

However, this also suggests a possibility for a further test of the rule's effects. If shortening the three-point line caused teams to draft taller players, lengthening the line should cause them to draft shorter players. Figure 4 explores this conjecture by applying a kernel smoother to average height by draft position, in a manner similar to Figure 3. However, in this instance, the figure shows separate averages for before, during, and after the shortened line period. The graph suggests that the demand for height, as measured by draft behavior, increased with the shortening of the three-point line and then decreased when the three-point line was lengthened. This also suggests that the earlier results are not just a statistical artifact of a secular trend toward drafting taller players over time.

Conclusion

The results in this article illustrate how the strategic response to a technological change can cause firm-level substitution of employees and the consequent labor market bias in value to move in an unexpected direction. In our case, the introduction of the three-point line increases the benefits of making shots farther from the basket which causes the defense to adjust their strategy to protect against the higher value of the outside shots. This adjustment by the defense leads to relative gains in productivity for taller players who shoot closer to the hoop and now face a lower level of defense.

We also find that the increase in the productivity of taller players resulted in changes in the labor market for NBA players with an increase in the demand for height in the NBA draft. Furthermore, we exploit two changes in the length of the three-point line that occurred in the 1990s when it was shortened and then later lengthened again and find that the demand for height in the NBA draft increased with the shortening of the three-point line and then decreased when it was lengthened, thus allaying concerns that the effect we observe with the introduction of the three-point line were simply driven by a time trend. These results highlight the reality that not all technical changes are of the capital augmenting variety, and that investigations of potential skill biased technical changes should consider the scope of possible strategic behavior. They also document the worker-level productivity effect of a technical change. Finally, they provide strong evidence that employers do substitute toward employees that become more valuable as the result of exogenously imposed technical changes.

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Note

1. The http://www.basketballreference.com data lists some players as hyphenated positions (e.g., Center-Forward). For these players, we set their position as the first position named (e.g., Center for the previously mentioned case).

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