Product Market Conditions and Job Design

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Abstract: By linking product market factors to job design, this paper provides an explanation to the puzzling question of why firms under rather similar labor market conditions sometimes adopt homogeneous, but other times heterogeneous, job designs.

Compared to broadly defined jobs (BDJs), narrowly defined jobs (NDJs) helps to save training cost. But, under NDJ, coordination is more difficult and the odds of a quality problem greater, which in the linear-city model adopted in this paper means a location shock to the firm. When consumer sensitivity to product specification (travel cost) is sufficiently high (low), a firm will (not) adopt BDJ to avoid a location shock and the resulting intensified price competition. In the intermediate range of travel cost, a duopolist prefers to let the other firm bear the extra training cost of BDJ, but would incur the cost itself if the other does not. In this range, if entry is simultaneous, multiple equilibria arise and they do not tell which firm will adopt BDJ or NDJ. If entry is sequential, the number of equilibria is reduced from three to one, in which the early comer will adopt NDJ and the late comer BDJ. A monopolist’s job design choice is always deterministic.

A job design may have a positive or negative social welfare implication depending on market structure and travel cost.

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1. Introduction

Explaining when and why firms would adopt heterogeneous human resource practices (HRPs) has been and still is a challenge to economists. In the past two decades, much effect has been made to understand why the HRPs of the Japanese firms are so different from those of the American firms. Hashimoto (1990) argues that Japanese workers receive more training and perform more tasks because, thanks to more rigorous pre-employment education, the cost of training is lower in Japan.\(^1\) Prendergast (1989), Glaeser (1991, 1992), Chang and Wang (1995), Acemoglu and Pischke (1998), and Morita (2001a, 2001b) show that labor markets can have multiple equilibria. So, while narrowly designed jobs, less training and higher turnover rates feature the American HRPs, the Japanese HRPs in another equilibrium have the opposite features. Carmichael and MacLeod’s (1992, 1993) multiple equilibria theory builds on an interesting incentive argument: Japanese firms train their workers for multiple skills so that these workers would worry less about their job security and be more supportive when new technology is being introduced.\(^2\)

While these models help us to better understand how labor market conditions affect firms’ HRPs, a question of great importance is yet to be more carefully studied: How do product market conditions such as competition and consumer preferences affect HRPs?\(^3\) Compared with labor market models, a model studying the relationship between product market conditions and HRPs would be particularly helpful in the following two closely related contexts.

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\(^1\) For a more general discusses the effect of the quality of labor pool on job design, see Lazear (1998, p.444).


\(^3\) Adam Smith (1937, pp.17-21) noticed that the division of labor is limited by the extent of the market. Carmichael and MacLeod (1993), Morita (2001b) and Bai and Wang (forthcoming) have parameters in their models that can be interpreted as product market effect.
First, at the individual firm level, it is hard to believe that a firm would typically design its HRP without certain product market objectives in mind, such as the extent to which they can control cost and cut price, or control product quality. Indeed, several studies of the experiences of the steel, commercial airline, automobile and other industries strongly suggest that the recent trend to adopt innovative HRPs is driven primarily by product market forces (see section 6 for details). Real-world experiences like these call for a theory that can help us to understand the relationship between product market conditions and firms’ HRPs.

Second, at the aggregate level, heterogeneity in HRPs exists not only between countries, but also within a country, an industry, or even a firm (see section 6 for examples). While labor market models are useful in explaining cross-country differences in HRPs, they do not intend, and would be far stretched, to explain heterogeneity in HRPs within an economy, where firms are in a unified labor market and face similar, if not identical, labor market conditions. For those who believe that firms do adopt HRPs with product market strategies in mind, a natural thing to do is to look beyond labor market at product market factors and examine how they might affect HRPs. It is of particular interest to see if, and when, these conditions lead to heterogeneity in HRPs, and when they do not.

This paper uses a linear-city model to study how product market conditions affect firms’ HRPs. We focus on firms’ job design and training decisions. In the paper, a job is identified with a set of tasks grouped together for a worker to perform: a narrowly defined job (NDJ) has fewer tasks grouped in it than a broadly defined job (BDJ). The basic tradeoff in job design is as

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4 “Innovative human resource practices” include multiskilling, multitasking, teamwork, quality circles, total quality management, and so on. Carmichael and MacLeod (1993) and Morita (2001b) discussed the complementarity among these practices. Ichniovski et al (1997) provided empirical evidence of positive correlations of these practices in the steel industry.

5 Gibbons and Waldman (1999, p.2375) noticed that, until recently, predictions on “job design were essentially non-existent” in economics.
follows. A firm can lower training cost by adopting NDJ because, to perform a more limited set of tasks, a worker does not need as many skills. However, under NDJ, coordination in production is more difficult because more communication is needed and/or workers do not communicate as well (due to the fact they are less trained and have a narrower view of the production process). When a mistake in communication occurs, the firm experiences a quality control problem leading to a failure to produce and deliver the final product as originally planned. In the setting of a linear market, product feature is unidimensional. A quality problem therefore means a “wrong” location, i.e., a location other than the one intended by the firm. The job design decision for a firm to make is whether to have NDJ and enjoy the low training cost advantage or incur the extra training cost under BDJ to better assure itself the right location.

The model finds that, given the expected magnitude and the probability of a shock, job design depends critically on the travel cost relative to that of training. This holds when the market has either a duopoly or a monopoly structure. This means that, when a deviation from the desired feature of the product leads to a greater loss of value for a consumer, producers have stronger incentives to better assure their locations.

6 Thinking of a given amount of “setup” time cost before starting each task as in Smith (1937, p.4) would have the same cost implication as more training. It is important to keep in mind that a lower upfront training cost is not the same as the final cost advantage of a lower cost to revenue ratio. How to achieve such a lower ratio through job design is exactly what this paper studies.

7 We hold this as true when communication is either direct between workers (as in a horizontal structure) or through a supervisor (as in a hierarchical structure).

8 See Koike (1984), Aoki (1986) and Lazear (1998, p.445) on the benefit of multiskilling to communication. In a clothing manufacturing plan in Scotland, established over 40 years ago and currently employs about 650 workers, the workers were originally each assigned to one sewing operation. Large buffer stocks exceeding the targets often built up between successive positions. In the mid-1990s, the plant changed to “group working cells”. A “cell” consists 8 workers with access to 20 sewing machines. Each worker works 3 – 5 different sewing operations successively and repeats the cycle. This reduced the throughput time, increased product flexibility and better ensured in-process quality (van de Meer and Gudim, 1996). This example and that of the pin factory (Smith, 1937) together captures the basic tradeoff in job design assumed in this paper.
The reason for a duopolist to care about location involves the strategic consideration of lessening price competition. Under duopoly, a lower travel cost means more intense price competition between the firms at any given locations. In the extreme case when travel cost is zero, location does not matter anymore and the competitive price prevails. As a result, there is no reason for a firm to incur the extra training cost to better ensure itself the “right” location to avoid price competition. It follows that, when the travel cost is sufficiently high relative to that of training cost, both firms will choose BDJ. When the travel cost is sufficiently low, both firms will choose NDJ, even though they would both be better off if they both choose BDJ. In the intermediate range of travel cost, the firms do not have a dominant strategy in job design. In this case, a firm prefers not to have BDJ if the other firm has BDJ so that the worst price competition is already avoided. But, if the other firm has NDJ, it is then in a firm’s own best interest to have BDJ. This means that, if the two firms are to simultaneously make their job design decisions, multiple equilibria will arise: either one firm choose BDJ while the other chooses NDJ, or both of them adopt a mixed strategy of choosing BDJ or NDJ at some predetermined probabilities. In either case, an individual firm’s job design is indeterministic. However, if the two firms make their job design decisions sequentially (perhaps because they enter the market at different times), the early comer will choose NDJ and thereby force the late comer to adopt BDJ (provided the early comer can credibly commit to the NDJ it has chosen). In any case, in this intermediate range of parameter values, BDJ and NDJ are both found in the market (for certain if the firms are in an asymmetric equilibrium or at certain probability if they are in a mixed strategy equilibrium).

For a monopolist, the kind of strategic consideration discussed above is absent. However, being at the right location is still desirable when consumer valuation of the product
and travel cost are both high. To see the reason, note that a high consumer valuation of the product means a high price of the product and also high marginal profit. With marginal profit high, the monopolist wants to fully cover the market. The maximal price to fully cover the market, however, has to be lower when travel cost is higher. When consumer valuation of the product and travel cost are both high, the monopolist has to cut price substantially to continue to fully cover the market when it is shocked away from the center of the market. The monopolist can adopt BDJ to prevent this from happening.

Social welfare is lower when the duopolists adopt BDJ because production cost and total travel cost are both higher. Although the producers themselves are better off, what they gain is a transfer from the consumers. When a monopolist adopts BDJ, production cost is higher but total travel cost is lower. Social welfare is higher (lower) if the travel cost is sufficiently high (low).

Sections 2 through 5 below introduce the model and derive the main results. Section 6 discusses the model and its empirical relevance. Section 7 concludes the paper.

2. The model

Our model of job design by firms in a linear market has the following specifications.

The market: The consumers are evenly distributed in a linear market of unit length in the range of [0, 1]. Travel cost in the market is \(tx^2\), where \(0 \leq x \leq 1\) is the travel distance and coefficient \(t\) > 0 a constant number. Consumer valuation of the product is \(v\). If \(p\) is the price of the product, a consumer purchases a unit of the product when \(v \geq p + tx^2\), or nothing otherwise.

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9 When travel cost is linear, the firms’ demand and profit functions both become discontinuous. Then it is likely that only a mixed strategy equilibrium exists in the price competition and the model becomes not easily tractable (see Dasgupta and Maskin, 1986; and Tirole, 1988, p. 280).
The producers: Two firms compete in the market to each maximize its own expected profit.  

Firm 1 is at location a and firm 2 at (1 – b), with 0 ≤ a ≤ 0.5 ≤ 1 – b ≤ 1, i.e., firm 1 is on the left side of firm 2.

Production technology: A product is produced with two parts (intermediate inputs) A and B. Labor is the only input used to produce the parts. The activities to produce the two parts are referred to as, respectively, tasks A and B. The two tasks have identical production functions in the form of

\[ q_m = f(L_m) = 2L_m, \quad m = A \text{ or } B \]

where \( L_m \) is the amount of labor input used in task \( m \). The parts contribute to the final product as in a Leontief production function. For simplicity, assume that a unit of the final output is produced when a unit of part A and that of part B are combined, and units of a part in excess of those of the other part do not contribute to the final output. Pairing the two parts requires no effort or cost. Total final output \( q \) is thus

\[ q = \min \{ q_A, q_B \} , \]

When equal amounts of labor are assigned to the two tasks, i.e., when the total labor hired \( L \) is divided equally between A and B so that \( L/2 \) units of labor is used in each task, total final output is

\[ q = q_A = q_B = L. \]

Workers and skills: Each worker inelastically supplies a unit of labor. \( L \) workers are needed when the production needs \( L \) units of labor.
Workers are identical before they are hired and trained so that, *ex ante*, they are equally qualified for a job. The worker is a utility maximizer with utility $u = w - e$, where $w$ is the worker’s wage and $e$ the training cost born by the worker.

A worker must receive training before she can perform a task. For a worker to perform task $m$, ($m = A$ or $B$), he must obtain skill $m$ through training. For a worker to perform both tasks, he must obtain both skills $A$ and $B$. Training costs the worker $c$ per skill;\(^{10}\) it is $c$ or $2c$, depending on whether a worker acquires one or both skills.

**Job design:** Each worker is assigned to a job identified with the task(s) to be performed by the worker. An NDJ contains either task $A$ or $B$, but not both. A BDJ contains both tasks $A$ and $B.\(^{11}\)

**Location shock and communication:** If firm 1 intends to be at location $a$ in the market, a shock may occur to shift it to the right of $a$. The distance of the shock is $\theta > 0$. If nothing is done to counterbalance the shock, firm 1 will end at $(a + \theta)$ instead.\(^{12}\) Similarly, a shock may occur to shift firm 2 to the left of its intended location $(1 - b)$. If nothing is done, firm 2 will be at location $(1 - b - \theta)$ instead. For simplicity, the values of $a$, $b$ and $\theta$ are assumed to be such that firm 1 will never be on the right side of firm 2.

Two signals are available suggesting that a shock has occurred. One signal is received and correctly understood by the workers with skill $A$ and the other by the workers with skill $B$.

\(^{10}\) This could be in the form of training time with low or no pay. Positive relationship between the number of tasks to perform and training and learning is also assumed by Prendergast (1995) in the setting of division of tasks between the manager and a subordinate.

\(^{11}\) The discussion on job design in this paper is different from that on how to assign workers to given jobs as discussed by Lazear and Rosen (1981), Waldman (1984a, b) and Gibbons and Waldman (1999), among many others, although both are about division of labor within firms.
Together, they reveal truthfully if the shock has occurred. A costless action can be taken to counter the effect of the shock. If the signals are communicated accurately between the two groups, the shock is perfectly understood and the action is effective, i.e., it will eliminate the effect of the shock and enable the firm to end at its intended location.\footnote{Whether communication is directly between the workers or through a supervisor is not important for our purpose. We could assume it is harder for workers with a single skill to correctly understand their supervisors than workers with more skills.} When communication between the workers in the two tasks is inaccurate, a wrong action is taken, i.e., no action is taken when the shock did occur, but an unnecessary action is taken when the shock did not occur. In either case, the firm will end at the wrong location. Let \( r \) be the probability of \footnote{Let \( r \) be the probability of inaccurate communication between the workers with different skills and \( s \) the probability that a shock occurs. The probability of a wrong action leading the firm to end at a wrong location is \( rs + r(1-s) = r \).} \( 0 < r < 1 \) when workers have only a single skill, and \( r = 0 \) when workers have both skills so that the signals are always understood accurately.\footnote{Imagine that, to produce an apple cider of a certain degree of sweetness, information of the apples used and that of another input, e.g., sugar, must be accurate. Weather conditions such as rainfall, temperature, etc., change from year to year and affect both apple and sugar quality. Cider production process needs to be fine-tuned accordingly to have the desired level of sweetness. This requires that the workers handling apples and those handling sugar understand each other. One can also think of a case of market shock. Suppose that the market is of unit length, but nature randomly assigns it to the range of \([0, 1]\) or \([1, 2]\). Signals are received by the workers in sales and production. If it is done right, an exchange of information leads to the correct understanding of the location of the market before production starts. Otherwise, the location of the market is misunderstood and a wrong product is produced.}

**Sequence of events:** The events in the model occur in the order of i through iv below.

i) Simultaneously, the two firms each choose a location it intends to be at. Each firm also chooses NDJ or BDJ for job design.
ii) Workers are hired. All hired workers go through a training period. The workers are trained for a single skill or both skills depending on whether a firm has chosen NDJ or BDJ in i above.

The employment contract specifies that, if a worker is eventually retained to participate in the production, he will be paid wage $w$ at the end of the production. If the worker is laid off before production is carried out, the worker will receive nothing from the employer. He receives instead unemployment benefit $UB = w$ from a third party.\textsuperscript{16}

iii) Signals of the shock are received. The signals are always correctly understood by the workers with trainings in both A and B, but, at probability $r > 0$, misunderstood by the workers with training only in A or B. A costless action is taken by the workers to try to eliminate the effect of the shock. The action is effective or not depending on correct understanding of the signals.

iv) The locations of the firms are realized. The firms each choose a price to maximize profit. Each firm also determines the number of workers to be retained to carry out the productoin. Surplus workers, if there are any, are laid off.

Production is carried out, product sold, revenue realized and the retained workers are paid according to the contract.

\textsuperscript{16} UB is the total value of monetary compensation from private and government insurance programs, leisure, and self-production. The firms can participate in an insurance program at a lump-sum cost to each of them. Such a lump-sum cost will not affect the analysis below as long as it does not lead to negative profit. Under these assumptions, laying off workers has no cost. It follows that the number of workers hired for training is never less than what is eventually needed to carry out the production.
Let \( d_i = \text{NDJ} \) or \( \text{BDJ} \) be the job design, \( n_i \) the location of firm \( i \) and \( w \) the worker’s reservation wage. Under the above assumptions, the optimization problem of firm \( i, i = 1, 2, \) is to

\[
\text{Max } E \left( \Pi_i(n_i, n_j, w_i, w_j), p_i(n_i, n_j, w_i, w_j), p_j(n_i, n_j, w_i, w_j), r_i, r_j \right), \quad i \neq j.
\]

subject to 1) worker’s participation constraint (PC) \( w_i > w + e_i \); and

2) \( n_i, r_i \) and \( w_i \) are functions of \( d_i, n_j, r_j \) and \( w_j \) functions of \( d_j \).

If \( d_1 = \text{BDJ}, n_1 = a \) at probability \( (1 - r_1) = 1 \). If \( d_1 = \text{NDJ}, n_1 = a + \theta \) at probability \( r_1 > 0, \) and \( n_1 = a \) at probability \( (1 - r_1) \). Similarly, if \( d_2 = \text{BDJ}, n_2 = 1 - b \) at probability \( 1 \). If \( d_2 = \text{NDJ}, n_2 = 1 - b - \theta \) at probability \( r_2 > 0 \) and \( n_2 = 1 - b \) at probability \( (1 - r_2) \). \( e_i = c_i \) if \( d_i = \text{NDJ}; e_i = 2c_i \) if \( d_i = \text{BDJ} \).

To maximize profit, the firm always chooses \( w_i = w + e_i \) to satisfy the worker’s PC.

### 3. Optimal job design

The optimization problem can be solved by folding backward. We first solve for the equilibrium prices of the two firms at given locations (with the restriction of firm 1 on the left of firm 2) and costs. We then solve for the optimal locations of the firms. After that, we examine if it is worthwhile for a firm to adopt BDJ and pay a higher wage in order to better assure itself the optimal location. The first two steps are standard in the spatial competition model. (See Tirole, 1988, p.279-282, for a concise presentation, which we follow closely.) However, since we do not require the two firms to be symmetric in their production costs, some additional complication in solving for optimal location may arise.

Following the standard exercise (see details in the Appendix), it is straightforward to show that, at given locations \( a \) (for firm 1) and \( 1 - b \) (for firm 2), the two firms’ respective profits are

\[
\Pi_1^* (p_1(w_1, w_2, a, b), p_2(w_1, w_2, a, b), w_1, w_2, a, b) = (p_1^* - w_1)x^* \quad (1)
\]
$$= [t(1 - a - b)(3 + a - b)/3][(3 + a - b)/6 + (w_2 - w_1)/2t(1 - a - b)]$$

$$= t(1 - a - b)(3 + a - b)^2/18, \quad \text{if } w_2 = w_1$$

$$\prod_2^*(p_1(w_1, w_2, a, b), p_2(w_1, w_2, a, b), w_1, w_2, a, b) = (p_2^* - w_2)(1 - x^*)$$

(2)

$$= [t(1 - a - b)(3 + b - a)/3][(3 - a + b)/6 + (w_1 - w_2)/2t(1 - a - b)]$$

$$= t(1 - a - b)(3 - a + b)^2/18, \quad \text{if } w_2 = w_1$$

From Equation 1, we can obtain

$$d\prod_1/da = [-t(3 + a - b)(1 + 3a - b)/18] + (w_2 - w_1)/6 \quad (3)$$

It follows that $d\prod_1/da < 0$ if the two firms have the same job design so that $w_2 - w_1 = 0$, or if firm 1 has BDJ and firm 2 NDJ so that $w_2 - w_1 = -c < 0$. These are cases where firm 1 seeks maximal differentiation. By symmetry, we know that firm 2 will choose $b = 0$ if both firms have the same job design, or if firm 1 has NDJ but firm 2 has BDJ.

But, if firm 1 has NDJ and firm 2 BDJ, the second term in $(d\prod_1/da)$ is positive, i.e., $w_2 - w_1 = c > 0$. The sign of $d\prod_1/da$ becomes ambiguous. To determine the optimal value of $a$ in this case, we first simplify Equation 3 by using the facts $w_2 - w_1 = c$ and $b = 0$ (on the basis that firm 2 wants maximal differentiation in this case). We then rearrange the terms and set $d\prod_1/da = 0$ to satisfy the first-order condition for maximization. These measures give us

$$d\prod_1/da = (t/18)(-3 - 10a - 3a^2 + 3c/t) = 0$$

$$-3a^2 - 10a + 3(c/t - 1) = 0$$

By the formula for square roots, we have

$$a^* = \frac{10 \pm [(-10)^2 - 4(-3)(3(c/t - 1))]^{1/2}}{-6}$$

$$= \frac{10 \pm [(-10)^2 + 36(c/t - 1)]^{1/2}}{6}$$
which means that, for $a^* > 0$, it is necessary that $t < c$. As long as $t \geq c$, the principle of maximal differentiation holds, i.e., no $a^* > 0$ exists. In the rest of the paper, we first assume that $t \geq c$ is true for convenience. Later, we will see that, under our assumptions of the values of $r$ and $\theta$, when $t < c$, the two firms will both have NDJ as their job design, anyhow. Since only when $t \geq c$ is it possible that the two firms do not both have NDJ, the principle of maximal differentiation always holds (see Tirole, 1988, p.281, on the principle).

When choosing a location at the very beginning of the game, a firm also needs to decide if it wants to have BDJ at cost $2c$ per worker to preempt a possible location shock $\theta$, or have NDJ at the lower cost $c$ and tolerate the shock. The answer to the question depends, of course, on how costly being at a wrong location is relative to a higher training cost. For concreteness, let us assume $r = 0.5$. We also assume $\theta = 0.5$, i.e., when the signals of the shock are miscommunicated and misunderstood, firm $i$ ($i = 1, 2$) will end at location $0.5$, while firm 1 intends to be at $a = 0$ and firm 2 at $1 - b = 1$. Qualitatively, these assumptions do not affect our analysis of the basic tradeoff in job design.

The two firms have four possible job design combinations: 1) they both have NDJ; 2) they both have BDJ; 3) firm 1 has BDJ and firm 2 NDJ; and 4) firm 1 has NDJ and firm 2 BDJ. The profits of the firms under each combination are given in Limma 1 below.

**Lemma 1:** If both firms have NDJ, either of them has expected profit $73t/288$.

If the firms both have BDJ, either of them has expected profit $t/2$.

If firm 1 has NDJ and firm 2 BDJ, their respective expected profits are $(121t/288 + 13c/24)$ and $(97t/288 - 13c/24)$.
If firm 1 has BDJ and firm 2 NDJ, their respective expected profits are \( (97t/288 - 13c/24) \) and \( (121t/288 + 13c/24) \).

These payoffs are summarized in the matrix in Figure 1. The first number in each cell is firm 1’s profit, the second number firm 2’s.

**Figure 1**: The payoffs to firms 1 and 2 under different job design combinations

<table>
<thead>
<tr>
<th>Firm 2</th>
<th>NDJ, ( w_2 = w + c )</th>
<th>BDJ, ( w_2 = w + 2c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDJ ( w_1 = w + c )</td>
<td>( 73t/288 ), ( 73t/288 )</td>
<td>( (121t/288) + 13c/24 ), ( (97t/288) - 13c/24 )</td>
</tr>
<tr>
<td>BDJ, ( w_1 = w + 2c )</td>
<td>( (97t/288) - 13c/24 ), ( (121t/288) + 13c/24 )</td>
<td>( t/2 ), ( t/2 )</td>
</tr>
</tbody>
</table>

Based on these payoffs, we have

**Proposition 1**:  
1) If \( t > 156c/23 \), both firms choose BDJ.  
2) If \( t < 13c/12 \), both firms choose NDJ.  
3) If \( 13c/12 < t < 156c/23 \), a firm prefers NDJ if the other firm chooses BDJ, but BDJ if the other firm chooses NDJ. The three possible equilibria are then (BDJ, NDJ), (NDJ, BDJ), and both firms play a mixed strategy.

The main idea of proposition 1 is easy to understand. When \( t \) is high, small deviations from the desired feature of the product increase the loss of value to the consumer. Having a

\[ \text{17 All proofs are in the Appendix.} \]
more differentiated product generates a much greater payoff when $t$ is higher because price competition is more effectively reduced. So, when $t$ is sufficiently high relative to the additional cost of adopting BDJ, the firms adopt BDJ to reduce the chance of landing too close to each other. When $t$ is sufficiently low, a locational deviation is not very costly to either consumers or the producers because price competition is strong whether the firms are close or far away from each other. It is therefore not worthwhile for the firms to incur the extra cost to avoid being too close.

Proposition 1 also contains some subtle insights on how competition affects a firm’s job design decision. First, when $t$ is small, the firms choose (NDJ, NDJ) not because they are better off than choosing (BDJ, BDJ). In fact, since $73t/288 < t/2$, the firms are always (weakly) worse off in the equilibrium of (NDJ, NDJ) than in (BDJ, BDJ). However, when $t < 13c/12$, (NDJ, NDJ) is the equilibrium because of the prisoners’ dilemma problem: When $i$ incurs the cost to avoid the worst price competition, $j$ ($j \neq i$) can avoid the cost but still enjoy the benefit. When $i$ does not incur the cost, $j$ does not want to incur the cost and let $i$ share the benefit.

Second, competition also leads to the possibility of coexistence of different job designs in the market. In the intermediate range of travel costs, neither firm has a dominant strategy. If the other firm chooses NDJ, a firm prefers BDJ to avoid too much price competition (in the expected sense). But, it prefers NDJ if the other firm chooses BDJ because the worst price competition is already avoided. The lack of a dominant strategy leads to three possible equilibria, two of them asymmetric and one symmetric. Although without further specification it is difficult to determine which equilibrium the firms will be in, all three equilibria have the implication that both BDJ and NDJ are expected to exist in this market.
An interesting and helpful extension of the discussion is to see how this indeterminancy (in picking up an equilibrium and knowing which firm would adopt which job design) or randomness in job design (as in the symmetric equilibrium) when \( t \) is in the intermediate range may be resolved. Suppose that, in the sequence of the events specified in the model, the location and job design decisions in i) are changed from being simultaneous to sequential, i.e., one of the two firms (say firm 1) makes the location and job design decisions before the other. Suppose that firm 1 can commit to its choice credibly. From the proof of Proposition 1, iii), and the discussion above, it is straightforward to conclude that

**Corollary 1:** If \( \frac{13c}{12} < t < \frac{156c}{23} \), firm 1 enters the market before firm 2, and firm 1 can credibly commit to the job design choice it made before firm 2 entered the market, firm 1 will have NDJ and firm 2 BDJ.

The gist of Corollary 1 is that, when the parameter values are in the proper range, the early comer will force the late comer to incur the high cost to avoid the worst post entry price competition. Firm 1 is better off than randomizing, while firm 2 worse off. Firm 2 no longer has the choice of randomizing between BDJ and NDJ because firm 1 has committed to NDJ and is not randomizing anymore.

The social welfare implication of job design is opposite to what the conventional wisdom might think: total economic welfare is lower in the equilibrium (BDJ, BDJ) than in (NDJ, NDJ). To see this, let us start with the puzzling question as why in the equilibrium (BDJ, BDJ) the firms’ payoffs are always higher than those in (NDJ, NDJ). In particularly, why, regardless of its value, does the higher training cost in BDJ never seem to matter in determining the net benefit of BDJ over NDJ, as long as BDJ is adopted? To solve the puzzle, one can carefully inspect
Equation 1 or 2. It shows that, as long as the costs are equal, their values do not affect a firm’s profitability in anyway. Regardless of the costs, the market will be shared according to locations only. As long as consumer valuation of the product $v$ is sufficiently high and the market is fully covered, prices can always be and are indeed raised to completely absorb the costs, passing them over to the consumers. This suggests that, although the firms are always better off in the equilibrium (BDJ, BDJ), the consumers are not. In fact, they are strictly worse off: they will be paying a higher price for the product and incurring a higher total travel cost when the firms are at the locations of $a = 0$ and $(1 - b) = 1$ than any other combinations of $a$ and $b$, except when $a = 1 - b = 0.5$. We have

**Proposition 2**: Under the duopoly structure, the equilibrium (BDJ, BDJ) has a total social surplus lower than (NDJ, NDJ).18

**4. Job design under monopoly.**

A duopolist’s main motivation to adopt BDJ is to strategically avoid too much price competition that occurs when locational shocks are not properly countered. Free of such a worry, would a monopolist ever want to incur the high training cost to assure itself of the desired location in the market? The answer is yes. Due to price consideration, the monopolist would also want to assure itself the right location when the consumers have both a sufficiently high valuation of the product $v$ and a sufficiently high travel cost $t$.

---

18 We should emphasize that the counter intuitive result that the consumers are always worse off when both firms adopt BDJ is obtained under two key assumption. First, although the training cost $c$ is higher under BDJ, it stays within the range that the market is fully covered. Second, each firm can choose only one location. When these assumptions are not satisfied, the result may not hold.
To see this, suppose that consumer valuation of the product \( v \) is high enough so that the market is fully covered. Suppose also that the monopolist’s location is \( a \). The price that fully covers the market and also maximizes profit is

\[
p(v, t, a) = \begin{cases} 
  v - t(1 - a)^2 & \text{if } a < 0.5 \\
  v - ta^2, & \text{if } a \geq 0.5.
\end{cases}
\]

This means that the optimal location is \( a^* = 0.5 \). Note that \( p^* = v - t/4 \) if \( a = 0.5 \); and \( p^* = v - t \) if \( a = 0 \) or 1.

Again, suppose that a shock to the right of the intended location may occur and the magnitude of the shock is \( \theta = 0.5 \). If the monopolist has NDJ, at probability \( r = 0.5 \), it is unable to take the appropriate action to eliminate the effect of the shock and will land at location 1. The expected profit is thus

\[
E(\Pi_m(v, t, n, c, p(v, t, n))) = (1/2)[(p^*(0.5) - c) + (p^*(1) - c)]
= (1/2)(v - t/4 - c + v - t - c)
= v - 5t/8 - c.
\]

If the monopolist adopts BDJ, its production cost is 2\( c \) and location \( a = 0.5 \) is assured. The expected profit is

\[
E(\Pi_m^*(v, t, 0.5, 2c)) = v - t/4 - 2c.
\]

Comparing the expected profit under BDJ and that under NDJ, we have

**Proposition 3**: A monopolist adopts BDJ if \( t \geq 8c/3 \), and NDJ otherwise.

Proposition 3 makes clear the monopolist’s motivation to have BDJ. To fully cover the market, the monopolist needs to lower the price of its product to accommodate the consumer at location 0 who incurs a higher travel cost when production moves to the right of the center of the
market. When travel cost \( t \) is sufficiently high, it is worthwhile for the monopolist to incur a higher training cost to avoid the shock and substantial price reduction caused by the shock.

When a monopolist adopts BDJ, is it welfare improving? The answer is that it depends. To see this, note that in this case maximizing social welfare is equivalent to minimizing total travel cost (TTC). When the monopolist is at the center of the market,

\[
TTC = 2 \int_{0.5}^{1} t(x - 1/2)^2 dx
= t/12.
\]

When the monopolist is at an end of the market,

\[
TTC = \int_{0}^{1} t x^2 dx
= t/3.
\]

It follows that the expected TTC under BDJ and that NDJ are, respectively,

\[
E(TTC|BDJ) = t/12
\]

\[
E(TTC|NDJ) = (1/2)[t/12 + t/3] = 5t/24.
\]

As anticipated, NDJ leads to a higher expected TTC, and the difference is

\[
5t/24 - t/12 = t/8.
\]  \hspace{1cm} (4)

BDJ leads to a social welfare gain if \( t/8 > c \), or \( t > 8c \). We have

**Proposition 4**: 1) When a monopolist adopts BDJ, it is welfare improving if \( t > 8c \). 2) The monopolist adopts BDJ too soon to be socially optimal.

5. The impact of market structure and market size on job design.
A comparison of the parameter ranges in which the monopolist (m) and the duopolists (1 and 2) choose BDJ or NDJ reveals how market structure may or may not affect job design. Such a comparison is shown in Figure 2 below, which is based on Propositions 1 and 3.

**Figure 2**: Parameter ranges of job designs under monopoly versus oligopoly.

<table>
<thead>
<tr>
<th>Parameter Range</th>
<th>13c/12</th>
<th>8c/3</th>
<th>156c/23</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2 have NDJ</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>m has NDJ</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1, 2 have 3 equilibria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m has BDJ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1, 2 have BDJ</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Such a comparison gives us

**Proposition 5**: In the range $t < 13c/12$ or $t > 156c/23$, changing from monopoly to duopoly does not affect job design. In $13c/12 < t < 8c/3$, NDJ is adopted under monopoly, but both NDJ and BDJ are adopted under duopoly. In $8c/3 < t < 156c/23$, BDJ is adopted under monopoly, but both NDJ and BDJ are adopted under duopoly.

The proposition tells us that there is a range of parameter values in which market structure, i.e., whether it is monopoly or duopoly in the current context, matters. However, there are also ranges of parameter values in which market structure does not matter. When $t$ is sufficiently small (large), a firm always adopts NDJ (BDJ) regardless of the competitive condition in the market.

Adam Smith (1937) once argued that the degree of specialization is a function of market size. Does market size matter to job design reflecting the degree of specialization inside a firm? If yes, how and why? Our model can be used to address these questions. It finds that, for any
given values of $v$, $t$, $c$, $r$ and $\theta$, firms will always adopt NDJ when the market is sufficiently large. The reason for this result here is not exactly because specialization is more important in a larger than in a smaller market. In fact, in our model, marginal cost of production is constant under both BDJ and NDJ so that, if market size matters, it would have nothing to do with scale economy. The result is due to the fact that the size of the market has implications for how travel cost (in the case of monopoly) or competition (in the case of duopoly) will affect price.

Consider the case of a monopolist first. Suppose that all the parameters, $v$, $t$, $c$, $r$ and $\theta$, are given and have values as assumed before. Let the size of the market be $s > 0$. It should be immediately clear that, with $t$ and $v$ given, the monopolist cannot fully cover the market when $s$ is sufficiently large because the travel cost would eventually become too high for consumers sufficiently far away from the producer. From this fact, we have

**Proposition 6**: A monopolist will adopt NDJ if the market is sufficiently large.

For example, for a monopolist to adopt NDJ, it is sufficient that under NDJ and at the profit maximizing price, the market left uncovered is of size $\theta$ or greater. The reason for the result is easy to see. When $\theta$ or more of the market is not covered, the monopolist can choose location $a = 0.5 - \theta$, rendering a location shock of magnitude $\theta$ (to the right) no effect on the firm’s total sale at the original price.

In the case of a duopoly structure, it is easy to show that

**Proposition 7**: When the market is sufficiently large, the duopolists will both adopt NDJ.

A general point is that, given $\theta$, when the market is larger, the cost of a location shock is always smaller and incurring the higher cost of BDJ is less worthwhile than when the market is
smaller. Simply speaking, the reason that firms will always adopt NDJ in a sufficiently large market is that they do not need to worry as much about losing customers (at the original price) when they fail to produce the intended product exactly.

It is worth noting that our analyses on the effect of market size on job design can be applied equally well to situations when market size is given but the travel cost t is sufficiently high. When the travel cost is sufficiently high, the firms again cannot fully cover a market with a given size. This means that a location shock has less effect on a firm’s profit. The firms are thus less motivated to have BDJ. When travel cost is sufficiently high and the portion of the market covered is sufficiently small, the effect of the shock will be sufficiently small to justify adopting NDJ by the firms in the market. This suggests that what really matters to job design is not the size of a market per se, but how much the market is not covered. It is the size of the uncovered portion of the market that determines how much price reduction a firm needs to make in case of a shock.


We first discuss some technical issues and then the empirical relevance of the model.

6.1. Discussions of assumptions and some technical issues.

In principle, jobs and training do not always have to happen together in a given firm, although, "as a practical matter (they are)...often linked” (Lazear, 1998, p.445). For example, workers can be trained for multiple skills and still assigned to narrowly designed jobs. Our model can be modified to accommodate the possibility of separating task groupings and training. One can, for example, use Adam Smith’s (1937, p.4) argument that specialization can improve dexterity to construct a production function with an increasing return to scale in either of the two
activities A and B, i.e., a worker spending her full time on an activity can produce more than twice of what she is able to produce in half of the time. When the gain from scale economy is sufficiently large, NDJ would be adopted. When the need to improve communication and scale economy are both great, the firm may find it the best to train workers for multiple skills to improve communication, but still assign them to narrowly designed jobs to increase productivity. However, BDJ is still possible if there are other gains to BDJ, such as even better communication among workers when they perform multiple tasks than when they only receive multiple training but not performing multiple tasks. To avoid unnecessarily complicating the model and to avoid being distracted from the main purpose of this exercise by letting the results of the model depend too much on subtle comparisons of many nonessential but possible factors, these “additional gains” from either BDJ or NDJ are left out of the model. Consequently, training and job design are assumed to have a one-to-one relationship in the model. A major benefit of such an abstraction is the generality of the model. While the model is specifically about job design, the idea it captures applies equally well to other HRPs. For example, one can easily think of a similar tradeoff in adopting quality circles: it requires more training for the worker, but has the benefit of reducing the odds of a mistake in the production process.

The model assumes that the shock will shift production location by distance $\theta$ at a given probability $r$. These assumptions can be relaxed without qualitatively affecting the main results and the core message of the model. $\theta$, for example, can be seen as the expected value of a continuous distribution of possible sizes of the shock. The density function of $\theta$ can replace $r$.

In the model, we allow shocks to occur only in one direction for each firm and thus not have a zero mean. This assumption is not as restrictive as it first looks. One can think of a model of $n$ firms on a circle as in Salop (1979). Symmetry among the firms and maximal
product differentiation would mean equal distances between any two adjacent firms on the circle. In such a setting, to an individual firm, being shocked to the left or the right of its desired location would have exactly the same meaning – it would be too close to another firm. Given the symmetry among the firms and the effect of a zero-mean shock to a firm when the shock goes either left or right, we for convenience in modeling may as well truncate the circle at the points of two adjacent firms, focus on the relationship between them, and study what happens when they are shocked closer. The linear market we used can be interpreted as the truncated portion of the circle.

One might have wondered about the importance of using a spatial model to study the question of the impact of market conditions on job design. Using a spatial model is desirable primarily because of the generality of the model. Empirically, many products are differentiable one way or another. Theoretically, markets of homogenous products can be considered a special case of spatial market with travel cost $t = 0$. When this is true, one would then need to answer two questions before discussing job design. First, while BDJ is sure to lead to a higher training cost, what is the benefit it provides to a firm? Second, are the firms competing in price as in a Bertrand model or in quantity like a Cournot model? Sticking to the idea that BDJ enables a firm to better respond to shocks and therefore better able to produce high quality products, it is natural to think that BDJ can produce products of higher value for the consumers, leading to an upward shift of the demand curve. Then the decision of job design is straightforward under either price or quantity competition. To see this, let the demand curve shift upward by $\Delta p$ when a high quality product is produced. If the two firms compete in price,

19 The symmetry has the plausible general meaning that deviation from the optimal location to either the left or the right is equally harmful. Note that, in such a setting, the technical problem that arises when thinking about a zero-mean shock in a linear city setting, i.e., the boundary of the market, also goes away.
BDJ (NDJ) is chosen if $\Delta p > c$ ($\Delta p < c$), for it will enable a firm to raise price by a magnitude between $c$ and $\Delta p$ and still take all customers from the competitor. The same condition holds for BJD under quantity competition, although the exercise is slightly more complicated.

### 6.2. Empirical relevance of the model.

Our model has the power of predicting and explaining possibly different job designs in the context where firms operate in a unified labor market and under rather similar conditions. There is abundant empirical evidence broadly consistent with the prediction. Using data of 694 US manufacturing establishments, Osterman (1994) finds that, in 1992, over 35 percent of the establishments with 50 or more employees had broad job designs. Within the US airline industry, while many adopted narrowly designed jobs, Southwest, People Express and other (successful or failed) newer airlines designed jobs more broadly, where pilots and managers would do baggage loading and flight attendants cleaning, ticketing and other ground services (Petzinger, 1995, p35, 129; O’Reilly and Pfeffer, 1996). GM’s Saturn (Geber, 1992) is a well-known example of different job designs within a firm. Similarly, in the US airline industry, a major airline company would sometimes create an “airline-within-an-airline” e.g., CALite (of Continental), New York Air (of Texas International), and Shuttle (of the United), to mimic Southwest’s job design. The strategy worked at some of them, e.g., New York Air, but was not very successful at others. (Petzinger, 1995, p129, 145; O’Reilly and Jeffrey, 1996, and personal interviews.) It would be difficult for traditional labor market models to explain these experiences of heterogeneity in job designs, and to explain them by different labor market conditions.

Our model shows that product market factors have a major impact on firms’ job design choices. It specifically shows that BDJs are more likely to be found in markets where consumers
are sensitive to product quality and, at the same time, price competition is present and producers will lose customers without lowering prices (when the market is fully covered and “narrow” for an individual firm). Both findings seem broadly consistent with evidence found in many empirical studies. For example, Osterman (1994) finds evidence “strongly confirming” that a market “with international competition” and “emphasizing service, quality, and variety of products rather than low cost” are among the most important variables determining who would adopt new HRPs. Ichniowski et al (1997) found that partial plant shutdowns were an important impetus for steel establishments to adopt new work practices. Teamwork at Saturn was intended to solve GM’s problems of poor quality and declining market shares (Geber, 1992; Lazear, 1998, p.515). Competition for market shares was a major reason for newer airlines emerged after deregulation to adopt BDJs. It was also a major reason for many older airlines to try to redesign their jobs (Petzinger, 1995).

Another prediction of our model is that late-comers to a market are more likely to adopt BDJ. This also seems largely true empirically. Looking at labor market models explaining US-Japanese differences in HRPs, Carmichael and Macleod (1993) concluded that a truly exogenous reason would be difficult to find and an evolutionary view would have to be adopted to understand why the US and Japan have distinctive HRPs. Our model suggests that the timing of entry into a market could be a major reason. Compared with their American counterparts, Japanese firms recovering from the ruins of the war can be seen as late comers in most industries. It is also worthwhile to note that, in the US airline industry, later comers were also typically the ones to adopt BDJ.20

---

20 When interpreting the experiences of late comers adopting BDJ, two additional issues are involved. First, Lazear (1998, p.451) argues that smaller firms should have less specialized jobs than larger firms. This could be a competing reason for why the new startup airlines have BDJ while the older ones have
An interesting extension of the discussion of the model’s empirical implications is that jobs are generally more broadly defined in production of very high quality and luxury items for the rich and narrowly defined for production of low quality items for lower income mass consumption. These predictions are based on the argument that travel cost may be positively associated with income because, if being at the best location is a normal good, the loss of not being at the best location should go up with income.\textsuperscript{21}

Due to poor general education, training cost for labor in many developing countries would be high. Meanwhile, the products produced by developing countries are often of high labor and low technology contents and with perfect or close substitutes (e.g., clothes made in Malasia and those made in Bangladesh). The findings of our model predict that producers of labor intensive manufacturing products in developing countries are likely to have NDJ and little training for their workers. The products they produce are likely to be of low quality.

The finding of lower total social welfare when the duopolists both adopt BDJs than when they adopt NDJs (Proposition 2) seems to have some bearing on some Japanese experiences. In Japan, the distribution system has a high service cost and great quality. But what many consumers want is cheaper things from discount stores (with likely some loss in quality). Only,

\textsuperscript{21} This extension is due to Waldman (from personal communication).
low cost services or merchandise are not always readily available in Japan so that many Japanese consumers would travel to the US to obtain them.

7. Concluding remarks.

We have argued that product market factors matter to a firm’s internal job design, and how these factors affect job design needs to be studied more carefully. By modeling the relationship between product market conditions and job design, we have fruitfully obtained a number of results that can help us to understand important but under-studied real-world economic phenomena, such as heterogeneity of HRPs within an economy, an industry or a firm and late comers’ preference for BDJs. We have also discussed the social welfare implications of different job design choices under different market structure and consumer preferences.

Industrial organization economics has the tradition of explaining a firm’s conduct by the structure of a market. Firms’ HRPs can either facilitate or hinder the implementation of a particular product market strategy. For a firm to successfully implement a product market strategy emphasizing quality, variety, service, competitiveness, etc., new HRPs with workers better trained and more extensively involved in the production process seems necessary. In contrast, a firm adopting a product market strategy that emphasizes cost minimization is likely to have narrowly defined and closely supervised jobs with little training for and little involvement of workers. Given the close relationship between a firm’s conduct and its HRPs, it seems worthwhile to treat them as a bundle and study how product market conditions simultaneously determine a firm’s choice of a competitive strategy and HRP, as well as other aspects of its internal organizational design. Grossman and Helpman (1999) and Meagher and Orbay (2000) have recently showed the fruitfulness of studying the relationship between product and other
organizational design variables.\textsuperscript{22} The relationship between product market conditions and job
design as a key aspect of organizational design can also generate valuable insights, as we have
shown in this paper.

\textsuperscript{22} Grossman and Helpman (1999) show how a firm’s integration, specialization and product variety
decisions depend on the degree of market competition. Meagher and Orbay (2000) show uncertainty in
consumer preferences affects the choice of organizational size and that of the structure of the information
processing hierarchy.
References:


Appendix

Algebra to obtain Equations 1 and 2.

If the two firms are located at $a$ and $1 - b$, the market share of firm 1 is $x$ where

$$p_1 + t(x - a)^2 = p_2 + t(1 - b - x)^2$$

which after rearranging is

$$x = a + \frac{1 - a - b}{2} + \frac{p_2 - p_1}{2t(1 - a - b)}.$$

The market share of firm 2 is

$$1 - x = b + \frac{1 - a - b}{2} + \frac{p_1 - p_2}{2t(1 - a - b)}.$$

The two firms’ profits are, respectively,

$$\Pi_1 = (p_1 - w_1)x$$
$$\Pi_2 = (p_2 - w_2)(1 - x)$$

From the first-order conditions, i.e., $\Pi_i'(p_i) = 0$, $i = 1, 2$, for optimization, we obtain the perfect subgame Nash equilibrium (optimal) prices as functions of the locations of the two firms and their costs.

$$p_1^* = w_1 + t(1-a-b)(3+a-b)/3$$
$$p_2^* = w_2 + t(1-a-b)(3+b-a)/3$$

It is easy to verify that the second order conditions for optimization are satisfied.

At the equilibrium prices, the market shares of the two firms are

$$x^* = a + \frac{1-a-b}{2} + \frac{w_2 + t(1-a-b)(3+b-a)/3 - w_1 - t(1-a-b)(3+a-b)/3}{2t(1-a-b)}$$

$$= a + \frac{1-a-b}{2} + \frac{w_2 - w_1 + 2t(1-a-b)(b-a)/3}{2t(1-a-b)}$$

$$= a + \frac{1-a-b}{2} + \frac{w_2 - w_1}{2t(1-a-b)} + \frac{(b-a)/3}{2t(1-a-b)}$$

$$= \frac{3 + a - b}{6} + \frac{w_2 - w_1}{2t(1-a-b)}$$

$$1 - x^* = 1 - \frac{3 + a - b}{6} + \frac{w_2 - w_1}{2t(1-a-b)}$$

$$= \frac{3 - a + b}{6} + \frac{w_1 - w_2}{2t(1-a-b)}.$$

So, at given locations and costs, the profits of the two firms are

$$\Pi_1^*(p_1(w_1, w_2, a, b), p_2(w_1, w_2, a, b), w_1, w_2, a, b) = (p_1^* - w_1)x^* \quad (1)$$
\[ \begin{align*}
&\quad= [w_1 + t(1-a-b)(3+a-b)/3 - w_1][(3+a-b)/6 + (w_2-w_1)/2t(1-a-b)] \\
&\quad= [t(1-a-b)(3+a-b)/3][(3+a-b)/6 + (w_1-w_2)/2t(1-a-b)] \\
&\quad= t(1-a-b)(3+a-b)^2/18, \quad \text{if } w_2 = w_1
\end{align*} \]

\[ \prod_2^* (p_1(w_1, w_2, a, b), p_2(w_1, w_2, a, b), w_1, w_2, a, b) = (p_2^*-w_2)(1-x^*) \quad (2) \]

**Proof of Lemma 1:**

1) If the firms both have NDJ, \( r_1 = r_2 = 0.5 \), and \( w_1 = w_2 = w + c \). The expected profit of firm i, \( i = 1, 2 \), is

\[ E(\Pi_i(n_i, n_j, w, p_i(n_i, n_j), p_j(n_i, n_j), r)) \]

\[ = (1-r)^2 \Pi_i^1(a, b, p_1(a, b), p_2(a, b)) + r(1-r)\Pi_i^2(a+\theta, b, p_1(a+\theta, b), p_2(a+\theta)) + r\Pi_i^3(a, b+\theta, p_1(a, b+\theta), p_2(a+\theta)) + r^2\Pi_i^4(a+\theta, b+\theta, p_1(a+\theta, b+\theta), p_2(a+\theta, b+\theta)) \]

Plugging \( r = 0.5 \) and \( \theta = 0.5 \) into this profit function and using the result of \( E(\Pi_1) \) given by

Equation 1 repeatedly to solve for \( \Pi_i^k \), \( k = 1 \) through 4, we obtain

\[ E(\Pi_i(n_i, n_j, w+c, w+c, p_i(n_i, n_j), p_j(n_i, n_j), 0.5, 0.5)) \]

\[ = (0.25) \Pi_i^1(0, 1, p_1(0, 1), p_2(0, 1)) + (0.25) \Pi_i^2(0.5, 1, p_1(0.5, 1), p_2(0.5, 1)) + (0.25) \Pi_i^3(0, 0.5, p_1(0, 0.5), p_2(0, 0.5)) + (0.25) \Pi_i^4(0.5, 0.5, p_1(0.5, 0.5), p_2(0.5, 0.5)) \]

\[ = (0.25)(t/2) + (0.25)(49t/144) + (0.25)(25t/144) + (0.25)(0) \]

\[ = 73t/288 \]

By symmetry between firm 1 and firm 2, we know this is also firm 2’s expected profit.
2) If the firms both have BDJ, \( r_1 = r_2 = 0 \), \( w_1 = w_2 = w + 2c \). The locations of the two firms are guaranteed at \( a = 0 \) and \( (1 - b) = 0 \). Using the result of Equation 1 (or 2), the expected profit is

\[
E(\Pi_i^*(0, 1)) = t(1 - a - b)(3 + a - b)^2/18, \quad i = 1, 2
\]

\[= t/2.\]

3) When firm 1 has NDJ and firm 2 BDJ, \( w_1 = w + c \) and \( w_2 = w + 2c \). Firm 1 is at \( a = 0 \) with probability \( r_1 = 0.5 \) and at \( a = 0 \) with \( (1 - r_1) = 0.5 \). Firm 2 is at \( (1 - b) = 1 \) for certain. From Equation 1, we obtain firm 1’s expected profit

\[
E(\Pi_1(n_1, n_2, w_1, w_2, p_1(n_1, n_2, w_1, w_2), p_2(n_1, n_2, w_1, w_2), r_1, r_2))
\]

\[= (0.5)\Pi_1^1(0, 1, w+c, w+2c, p_1(0, 1, w+c, w+2c), p_2(0, 1, w+c, w+2c))
\]

\[+ (0.5)\Pi_1^2(0.5, 1, w+c, w+2c, p_1(0.5, 1, w+c, w+2c), p_2(0.5, 1, w+c, w+2c))
\]

\[= (0.5)[t/2 + (w_2 - w_1)/2] + (0.5)[(25t/144 + 7(w_2 - w_1)/12]
\]

\[= 121t/288 + 13(w_2 - w_1)/24
\]

\[= 121t/288 + 13c/24.
\]

\[
E(\Pi_2(n_1, n_2, w_1, w_2, p_1(n_1, n_2, w_1, w_2), p_2(n_1, n_2, w_1, w_2), r_1, r_2))
\]

\[= (0.5)\Pi_2^1(0, 1, w+c, w+2c, p_1(0, 1, w+c, w+2c), p_2(0, 1, w+c, w+2c))
\]

\[+ (0.5)\Pi_2^2(0.5, 1, w+c, w+2c, p_1(0.5, 1, w+c, w+2c), p_2(0.5, 1, w+c, w+2c))
\]

\[= (0.5)[(t/2 + (w_1 - w_2)) + (0.5)[(25t/144 + 7(w_1 - w_2)/12]
\]

\[= 97t/288 - 13c/24.
\]

4) When firm 1 has BDJ and firm 2 NDJ, \( w_1 = w + 2c \) and \( w_2 = w + c \). Firm 1 is at \( a = 0 \) for certain. Firm 2 is at \( (1 - b - \theta) = 0.5 \) with probability \( r_2 = 0.5 \) and at \( (1 - b) = 1 \) with \( (1 - r_1) = 0.5 \). By symmetry and from what we obtained in 3), we have

\[
E(\Pi_1) = 97t/288 - 13c/24
\]

\[
E(\Pi_2) = 121t/288 + 13c/24 \quad Q.E.D.
\]

**Proof of Proposition 1**: Suppose firm 2 has BDJ, it is worthwhile for firm 1 to have BDJ as well if
\[ t/2 - [(121t/288) + 13c/24] > 0 , \text{ or} \]
\[ t > 156c/23. \]

Suppose firm 2 has NDJ, it is worthwhile for firm 1 to choose BDJ if

\[ [(97t/288) - 13c/24] - 73t/288 > 0 , \text{ or} \]
\[ t > 13c/12. \]

Since \( 156(d_2-c_1)/23 > 13(d_1-c_2)/12 \), the conclusion is that if \( t > 156(d_2-c_1)/23 \), firm 1’s dominant strategy is to adopt BDJ. Given the symmetry between the two firms, the Nash equilibrium in the game is \( (BDJ, BDJ) \). This proves 1).

Reversing the two inequalities above, we can conclude that firm 1’s dominant strategy is NDJ if \( t < 13c/12 \). By symmetry, NDJ is also firm 2’s dominant strategy. This proves 2).

When \( 13c/12 < t < 156c/23 \), firm 1 will choose BDJ if firm 2 has NDJ because \( [(97t/288) - 13c/24] - 73t/288 > 0 \). But it will choose NDJ if firm 2 has BDJ because \( t/2 - [(121t/288) + 13c/24] < 0 \).

By symmetry, we know that neither firm has a dominant strategy, which is 3). Q.E.D.

**Proof of Corollary 1**: Recall that, when \( t < 156c/23 \), firm 1 is better off in \( (NDJ, BDJ) \) than in \( (BDJ, BDJ) \) or any other cell. So, whatever the probabilities are at which firm 1 and firm 2 randomize between BDJ and NDJ, firm 1 is better off to have \( (NDJ, BDJ) \) for certain. When \( 13c/12 < t \), firm 2 is better off to have BDJ, given that firm 1 already has NDJ. Q.E.D.

**Proof of Proposition 2**: Since the worker obtains the same utility level under any circumstances, total social surplus is given by consumer valuation of the product minus total travel cost and total production cost, which are both higher under BDJ. Q.E.D.

**Proof of Proposition 3**: From Equations 5 and 6, we know that the monopolist adopts BDJ if

\[ (v - t/4 - 2c) - (v - 5t/8 - c) > 0 \, , \]
which after rearranging and cancelling terms is

\[ \frac{3t}{8} > c , \text{ or} \]

\[ t > \frac{8c}{3} . \quad \text{Q.E.D.} \]

**Proof of Proposition 4**: From Equation 4, we know that total travel cost is lower under BDJ than under NDJ by \( t/8 \). But production cost is high under BDJ by \( c \). BDJ leads to higher total social surplus if \( t/8 > c \), which after rearranging is the condition in 1). Comparing this with the condition for the monopolist to adopt BDJ, \( t > \frac{8c}{3} \), proves 2). Q.E.D.

**Proof of Proposition 5**: The proposition is based on Figure 2. Q.E.D.

**Proof of Proposition 6**: The monopolist can choose location \( a \) such that, at the optimal price, market in \([0, x]\) is covered, with \( s - x = \theta \). If \( a \) is the location that maximizes profit, so is \( a + \theta \) (as well as anywhere between \( a \) and \( a + \theta \)), because, when the monopolist ends at \( a + \theta \), the market covered changes to \([\theta, s]\), which is of the same size at the same optimal price. The monopolist is, therefore, not suffering any adverse effect of the locational shock on profit. It is thus always worse off to incur a higher training cost to assure itself of location \( a \). Q.E.D.

**Proof of Proposition 7**: When \( s \) is so large that each firm covers less than 1/2 of the market even when they are located at, respectively, \( a = s/4 \) and \( (1 - b) = 3s/4 \), the duopolists are actually turned into monopolists in their own respective markets. The rest of the proof is then the same as in Proposition 6 above. Q.E.D.