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## Variation in labour skills and offshoring across time zones

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## **Variation in labour skills and offshoring across time zones**

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# Variation in labour skills and offshoring across time zones

## Abstract

The paper extends Dei (2010) to check the role of time zone difference on offshoring of service tasks when the quality of workers varies between the partner countries. We frame a model where partner countries are located in non-overlapping time zones, and the skill level of the partner country workers is lower than that of the domestic workers. In our model, service production is divided into two sequential stages, and output is a supermodular function of the skill of workers and time. The problem of the service producers is to choose between domestic production and offshoring. Domestic production employs high-quality skilled labours but the time management is inefficient. On the other hand, offshoring to a non-overlapping time zone helps a firm to work round the clock, but the low quality of skilled labour lowers the output, though they cost less. In such a framework, we check under what conditions offshoring is beneficial. The analysis provides a condition where firms decide to offshore through a tradeoff between time and skill. We observe that the lesser of 24 hours domestic production use, the lower will be the threshold of acceptable skill level. Results show that offshoring to a different time zone is beneficial even when the complexity of stages of production vary. However, it is observed that only the relatively less-critical task is offshored. We further observe that availability of domestic low-quality labour does not benefit the firm, but foreign low-quality labour can be beneficially utilized through time-zone exploitation.

**JEL Classification:** F1; F23; J24; L23; L86

**Keywords:** Offshoring; Skill; Time Zones; Virtual Trade; Services

## 1 Introduction

Offshoring of service activities to other countries has become a common phenomenon now. With the development of information and communication technology (ICT), service offshoring is becoming more convenient. ICT helps services to be traded virtually, which has increased the range of services that can be offshored beyond national boundaries. Handing over a particular work to other countries requires considering many factors like cost, infrastructure, trade laws and policies, location, time, skill, etc. In this paper, we consider the timing of production and skill level of partner countries while deciding for offshoring a service-production task. There are several papers that consider inter- or intra-country differences in skill of labours and show their effect on offshoring and international trade. Notable among them are Bombardini et al. (2012, 2014), Grossman and Maggi (2000), Ohnsorge and Trefler (2007), Fable (2004), Ngeinthei et al. (2013), Dei (2010), Grossman (2004), Antras et al. (2006), Ngeinthei and Dei (2012), etc. From the above-mentioned papers, we get to know that in the presence of variation of skill, both high and low-quality labours are required for production depending on the technology. When the technology of production is supermodular, workers of similar skill are chosen; on the other hand, when technology is submodular, it becomes optimal to combine workers with dissimilar skills. In our paper, extending Dei (2010), we take a supermodular production function and check whether similar or dissimilar workers are chosen when there is an option of offshoring service provision activities to a country located in a different time zone.

Again, time zone difference of trading countries has recently gained focus as an independent driver of service trade.<sup>1</sup> Marjit (2007) and Kikuchi (2009) are the seminal papers that show differences in time zones can positively benefit service producers. In what follows, Matsuoka and Fukushima (2010) claim that if communication cost is low, fragmenting service-production activities between different time zones is more beneficial than producing domestically in day-night shifts. Kikuchi (2011) and Marjit et al. (2020) are two important books in this line of recent development in international trade that succinctly show the effects of trading

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<sup>1</sup> When time zones are different, the working hours (daytime) of one country do not overlap with the daytime of the other country. Therefore, a work starts in one country and at the end of the working day, the semi-finished work is digitally transferred to the other country where the working hours have just begun. In this way, a task continues round the clock, where each country adds value to the work in their regular working hours and transfers it to the other country when their day ends. Thus, offshoring to a country located in a different time zone helps to utilize full 24 hours.

across time zones on factor prices, output, and sectoral distribution of factors. However, there is a real dearth of papers where difference in workers skill has been considered while examining the role of time zone difference. Therefore, our paper fills this gap in the literature by identifying the role of time zones when the skill level of partner countries varies. Inter-country differences in quality of labour can arise because of difference in the pace of development, technology of production, difference in quality of educational intuitions, etc. Further, individual skills can also differ depending on their communication ability, health, gender, reasoning ability, etc. (Grossman 2013, Ohnsorge and Trefler 2007, Inaba 2019). Thus, skills can be seen in multidimensional way and it is likely that firm may not find exactly the desired level of skill while offshoring, which can make other countries' workers to be labeled as low quality. Our paper, however, does not deal with the reason behind difference in skills or quality but considers that the quality of skilled labour present in the partner country is relatively low. Specifically, in this paper we check the conditions for offshoring when trading countries' skill levels are not homogeneous.

We extend the theoretical model of Dei (2010) that follows the o-ring production theory of Kremer (1993).<sup>2</sup> In Dei (2010), output is a supermodular function of quality of labours. Dei (2010) compares the cost of different options of production and checks the condition of offshoring when qualities of workers vary. The result of Dei (2010) expresses that peripheral tasks are offshored but complex tasks are not. Following this, we develop an extension of Dei (2010) by incorporating time as a factor that influences output together with skills of labour. Then we compare the cost of different production organization to seek the condition under which offshoring is beneficial given a tradeoff between time and quality. We first consider the case where each stage of production is equally important for the final output; then as in Dei (2010), consider the case where the importance of each stage differs. Further, unlike Dei (2010) we check whether offshoring is beneficial when both low and high quality labours exist in the home country.

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<sup>2</sup> The name "o-ring" comes from the incident that happened in 1986 where the space shuttle "Challenger" exploded because of a defective o-ring that failed to function properly. This incident revealed that defect in a single input reduces the value of the whole product. Following this, the theory formulated by Kremer (1993) was named o-ring theory and the production function is called o-ring production function. In o-ring theory, production function is supermodular which implies inputs are complementary to each other. Better performance of one input increases the productivity of all other inputs. Similarly, if any input is defective it reduces the productivity of other inputs.

The paper is divided into the following sections. In section 2, we build an extension of Dei (2010) where output depends on both skill of input and timing of production. Following this, we derive the condition for which utilization of time zone difference is beneficial. In section 3, we analyze the offshoring condition when the importance of stages of production differs. In section 4, we extend the basic model of section 2. Here, the home country has both high and low-quality skilled labours and the partner country has only low-quality skilled labours. In such a framework, we examine if production is still offshored. Section 5 concludes the paper.

## 2 The Basic Model under Autarky

We consider two countries located in non-overlapping time zones, country *A* and country *B*. Both countries produce two goods, *X* and *Y*. We assume competitive markets, and workers in each country are homogeneous and immobile across countries. However, labours of country *A* are of higher quality/skill than country *B*. Further, only 12 hours of daytime is utilized for work in both the countries. In country *A*, the production function of good *X* is

$$X = q$$

Here *q* is the skill of country-*A* worker. *q* can also be regarded as the productivity parameter.<sup>3</sup> *X* requires only one worker for production and output is directly dependent on the skill of the employed worker. Production of *X* is completed in 12 hours. On the other hand, *Y* production is divided into two stages, each stage requires one worker and each stage is accomplished in 12 hours. We assume both the stages contribute equally to the final output. The production function of *Y* is

$$Y = tq_1q_2$$

Here *Y* is a supermodular function of *t* and skill,  $q_i$  ( $i = 1,2$ ); suffix 1 and 2 denote stages of production. Since workers are homogeneous,  $q_1 = q_2 = q$ (say). Therefore,

$$Y = tq^2 \tag{1}$$

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<sup>3</sup> Alternatively, following Kremer (1993), *q* can be taken as the probability of completing a task without any mistakes, the main essence of o-ring production function. We assume firms to be risk-neutral and thus we do not consider the distinction between expected output and actual output.

$Y$  is a time-sensitive service; if there is delay in production the output falls.  $t$  in equation (1) is the timing parameter; it indicates how much of 24 hours of a day a particular production strategy can use. If production continues round the clock then there is no loss in output, this means  $t = 1$ . However, if 24 hours are not utilized continuously the value of  $t$  becomes less than one ( $t < 1$ ) which lowers the output.<sup>4</sup> Therefore the range of  $t$  is  $0 < t \leq 1$ . This idea follows from Marjit (2007) and Mandal (2015). In the autarky situation, where only daytime is utilized for work, we take  $t = t_D = 0.5 < 1$ . Following this, equation (1) becomes

$$Y = t_D q^2$$

Therefore,  $t$  acts as a technology parameter which affects the contribution of skill towards the final good. Here, as we have taken an o-ring production function, even though the skill level of workers is high but because of lower value of  $t$  the final output is low. This triggers  $Y$  producers to search for alternative production strategies.

Similarly, for country  $B$ , production function of  $X$  is  $X^B = q^B$ ; and that of  $Y$  is  $Y^B = t q_1^B q_2^B = t_D q^{B^2}$  (as workers are homogeneous within the country and  $t = t_D$  under autarky). Here  $q^B$  is the skill of a worker in country  $B$ . We assume  $0 < q^B < q \leq 1$ . Therefore, it is apparent that  $X^B < X$  and  $Y^B < Y$  as  $q^B < q$ . Following Kremer (1993) we assume that quality cannot be substituted by quantity, i.e., two (or more) lower-quality workers cannot be substituted for one high-quality worker.

Since we have assumed perfectly competitive markets, under autarky, we have, for country  $A$

$$p_X = \frac{w}{q} \tag{2}$$

$$p_Y = \frac{w + w}{t q^2} = \frac{2w}{t_D q^2}$$

---

<sup>4</sup> This is similar to the iceberg effect of delivery cost as mentioned in Kikuchi (2011), where delay in delivery makes the output lose its value.

where  $w$  is the wage rate in country  $A$ ,  $t_D (< 1)$  is the value of  $t$  for domestic production and  $p_j$  ( $j = X, Y$ ) is the price of good  $j$ . Similarly, with  $w^B$  being the wage in country  $B$  and  $p_j^B$  the price of good  $j$ , we have

$$p_X^B = \frac{w^B}{q^B} \tag{3}$$

$$p_Y^B = \frac{2w^B}{t_D q^{B^2}}$$

As in Dei (2010), we take  $X$  to be the numeraire by setting its price as unity (i.e.  $p_X = 1$  and  $p_X^B \equiv 1$ ).<sup>5</sup> Also, for brevity of the analysis,  $q = 1$ .

Therefore from equation (2),

$$w = q \Rightarrow w = 1; \tag{4}$$

$$\text{and } p_Y = \frac{2}{t_D}$$

Similarly from (3),

$$w^B = q^B; p_Y^B = \frac{2}{t_D q^B} \tag{5}$$

## 2.1 Offshoring decision

As mentioned earlier, a lower value of  $t$  reduces the output of  $Y$ . However, when there is an option to offshore one of the stages of  $Y$  to country  $B$ , the value of  $t$  will rise. This is because

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<sup>5</sup> This is a very crucial assumption of our model. According to this assumption, cost of  $X$  in both the countries is same, which means offshoring of good- $X$  production does not occur. Further,  $p_X = p_X^B = 1$  implies the ratio of wage to skill in both the countries is same. This means wage difference will not induce offshoring of  $Y$  (Dei 2010). Therefore, this assumption helps to highlight the role of time zones in affecting the decision of offshoring which will be seen in the next section.



country  $B$  is located in a non-overlapping time zone with respect to country  $A$ . Let the value of  $t$  be  $t_o$  when one of the stages of  $Y$  is offshored. Because of non-overlapping time zone, when the daytime of country  $A$  ends, the daytime of country  $B$  starts. Therefore, the first stage is finished in country  $A$  during its 12 hours of daytime, and the semi-finished task is virtually traded to country  $B$  where the second stage is performed during the next 12 hours of the calendar date.<sup>6</sup> In this way, work continues for 24 hours which makes  $t_o = 1$ , thus positively affecting the output. However, the quality/productivity of labour is low in country  $B$ . Therefore, there is a tradeoff between time and quality. Thus, the question boils down to will a firm offshore to a country endowed with relatively lower quality of skilled labours in order to achieve timely production.

Hence the firm is confronted with the problem of choice of the mode of production. Note that total production time will be reduced when only one stage of  $Y$  is offshored. As a result, the firm can either produce both the stages domestically or offshore any one stage. Cost under each strategy of production is given as:

Choice 1: Cost when both stages are produced at home:

$$C(1,2) = \frac{w + w}{q^2 t_D}, t_D < 1 \quad (6)^7$$

Choice 2: Cost when one stage is produced at home and other stage in country  $B$  (i.e. cost when non-overlapping time zone is exploited):

$$C(1,2^B) = C(1^B, 2) = \frac{w + w^B}{q q^B t_o} = \frac{w + w^B}{q q^B}; \text{ since } t_o = 1 \quad (7)$$

The superscript ' $B$ ' in  $C(1,2^B)$  and  $C(1^B, 2)$  denotes the stage is offshored to country  $B$ .

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<sup>6</sup> Producing across non-overlapping time zones gives country- $A$  firms the opportunity to save one calendar date by providing two 12-hour workdays within the same calendar date. If production takes place domestically, the first stage is accomplished in the 12-hour workday of first calendar date, whose 12 hours of nighttime remains idle. The second stage is completed on the next calendar date. On the other hand, in case of non-overlapping time zones, first stage is completed in 12 hours in country  $A$  and the next 12 hours of work is done in country  $B$  within the same calendar date of country  $A$ . Thus, one calendar date is saved when time zone difference is utilized. For more details check Mandal and Prasad (2020).

<sup>7</sup> Note that this cost equation is valid even when the firm goes for both day and night shift work:  $C(1,2) = \frac{(w^D + w^N)}{q^2 t}$ , where  $t = 1$  but the nighttime wage ( $w^N$ ) is more than the daytime wage ( $w^D$ ). We ignore such possibility and assume only day-shift work.

Offshoring will be beneficial when

$$C(1,2) > C(1^B, 2)$$

Putting the values from (6) and (7)

$$\Rightarrow \frac{w + w}{q^2 t_D} > \frac{w + w^B}{q q^B}$$

Putting the values of  $w$  and  $w^B$ ,

$$\Rightarrow \frac{2q}{q^2 t_D} > \frac{q + q^B}{q q^B}$$

As  $q = 1$ ,

$$\begin{aligned} \Rightarrow \frac{2}{t_D} &> \frac{1 + q^B}{q^B} \\ \Rightarrow 2q^B - t_D q^B &> t_D \\ \Rightarrow q^B &> \frac{t_D}{2 - t_D} \end{aligned} \tag{8}$$

Inequation (8) gives us the condition under which it will be beneficial for the firm to offshore one of its stages when  $t_D < 1$  and  $q^B < 1$ . The condition shows that the values of  $q^B$  and  $t_D$  are important while deciding to offshore to a different time zone. In figure 1 we have plotted  $t_D = 1$ ,  $q^B = 1$  and  $q^B = \frac{t_D}{2-t_D}$ . The condition for offshoring is satisfied within the region  $OBD$ .

The region gives the combinations of  $q^B$  and  $t_D$  for which offshoring can take place even when  $q^B < q$ . At a particular value of  $t_D$ , the distance between the line  $DB$  and curve  $OB$  provides the range of  $q^B$  for which offshoring can be beneficial and below which the skill of  $B$  will not be usable by  $A$ . For example, in our model  $t_D = 0.5$  which implies from condition (8) that  $q^B$  must be greater than or equal to 0.33. If  $q^B < 0.33$ , such as at point  $J$ , it falls outside the offshoring region  $OBD$  and hence, offshoring does not take place. Nevertheless as long as  $t_D < 1$ , offshoring to lower skilled workers located in a different time zone will be beneficial given

condition (8) is satisfied.<sup>8</sup> Therefore, even when the skill of workers varies, the difference in time zones gives rise to the possibilities of offshoring.<sup>9</sup>

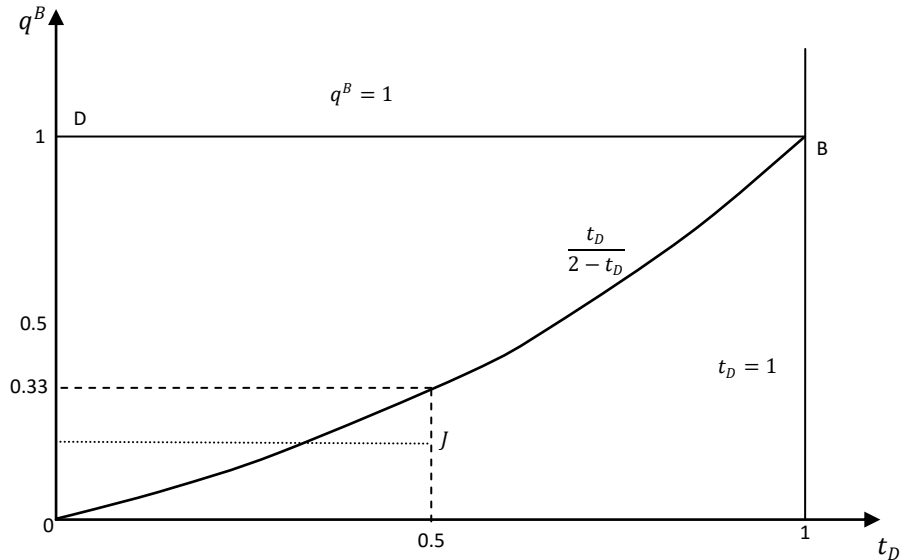


Figure 1: The offshoring condition

The above result may seem to contradict the results of papers such as Grossman and Maggi (2000), Ngeinhi et al. (2013) etc., where it is proposed that when production function is supermodular, homogeneous workers are preferred over heterogeneous labour group. However, in our model  $t$  plays an important role in elevating the quality of workers. So even when workers are heterogeneous the importance of timely production makes foreign labours skilled enough to be utilized. Therefore, even when output is a supermodular function of skills of labour we encounter matching of heterogeneous workers.

From the above analysis, we propose

<sup>8</sup> One might think that the productivity in case of offshoring is lower than the autarkic case as skill of country  $B$  is lower. However, the values of  $t_D$  and  $q^B$  decide for which case productivity is more. This has been shown in the Appendix.

<sup>9</sup> Note that, if country  $A$  and  $B$  were in the same time zone then  $C(1,2) < C(1,2^B)$  as  $q^B < 1$ . This implies, in our model offshoring takes place only because of difference in time zones and not because of differences in wage of the two countries.

**Proposition 1:** When output is a supermodular function of skill of labours and timing of production, time zone difference can induce firms to offshore to a country endowed with lower skill if  $q^B > \frac{t_D}{2-t_D}$ . ■

Further, we observe that curve  $OB$  in figure 1 is convex which implies when  $t$  rises, the minimum level of skill required from country- $B$  workers rises at an increasing rate. This is because with rise in  $t$  the domestic cost of production falls, and to maintain the offshoring condition (8), skill of country- $B$  workers must rise. However, the percentage fall in  $C(1,2^B)$  because of rise in  $q^B$  is less than the percentage fall in domestic cost resulting from rise in  $t$ . This can be seen in figure 2.

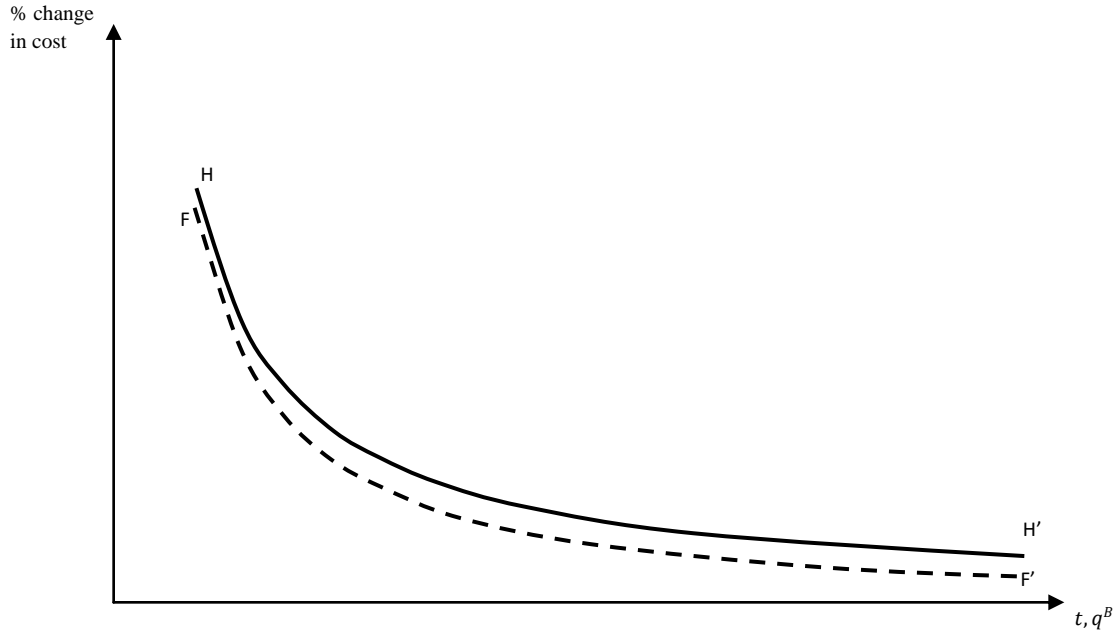


Figure 2: Percentage change in costs of production

The  $HH'$  curve in figure 2 shows the percentage change in  $C(1,2)$  with each unit rise in  $t$ , whereas  $FF'$  shows the percentage change in  $C(1,2^B)$  or  $C(1^B, 2)$  with each unit rise in  $q^B$ . It can be observed that the percentage change in  $C(1,2)$  is always greater than that of  $C(1,2^B)$ . Therefore, to maintain the offshoring condition,  $q^B$  should rise more than  $t$ . As a result,  $OB$  is convex to the horizontal axis of figure 1. Thus, we have the following proposition.

**Proposition 2:** *When  $t$  rises, the threshold for acceptable skill level also rises at an increasing rate.* ■

### 3 When importance of stages increases with value addition

In the previous section, we considered that each stage of  $Y$  contributes equally to the output. However, this section considers the case in which the contribution of the second stage is higher. The second stage utilizes the semi-finished product prepared in the first stage; any fault in the second stage will destroy the work done in the first stage.<sup>10</sup> This makes the second stage more crucial. Following Dei (2010), the production function of  $Y$  will be

$$Y = q_1 q_2^2 t$$

The production function of  $X$  remains same as in the previous section. The autarkic price of both the goods in country  $A$  are

$$p_X = \frac{w}{q}$$

$$p_Y = \frac{w + w}{t q_1 q_2^2}$$

Since  $q_1 = q_2 = q$  and  $t = t_D$  under autarky,  $p_Y = \frac{2w}{t_D q^3}$

And for country  $B$

$$p_X^B = \frac{w^B}{q^B}$$

$$p_Y^B = \frac{2w^B}{t_D q^{B3}}$$

Similar to the previous section, taking  $X$  as numeraire and  $q = 1$ , we get ,  $w = 1$ ,  $p_Y = \frac{2}{t}$ ,

$$w^B = q^B, \text{ and } p_Y^B = \frac{2}{t q^{B2}}.$$

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<sup>10</sup> This was precisely the idea of o-ring production function.

With the option of offshoring, the firm has to choose between the following strategies:

Choice 1: To produce both the stages with domestic labour

Choice 2: To produce only first stage with domestic labour

Choice 3: To produce only second stage with domestic labour

The average cost for the three choices will be, respectively

$$C(1,2) = \frac{2w}{q^3 t_D} = \frac{2}{t_D} \text{ since } w = 1 \text{ and } q = 1$$

$$C(1,2^B) = \frac{w + w^B}{t q q^{B^2}} = \frac{1 + w^B}{t_o q^{B^2}} = \frac{1 + q^B}{q^{B^2}}$$

$$C(1^B, 2) = \frac{w^B + w}{t_o q^B q^2} = \frac{q^B + 1}{q^B}$$

The firm will choose the strategy having the lowest cost. Note that for  $C(1,2^B)$  and  $C(1^B, 2)$ ,  $t = t_o = 1$  as one of the stages is offshored to a non-overlapping time zone. This implies production can continue for 24 hours if any of these choices are chosen. However, the average cost of choice 2,  $C(1,2^B)$ , is not the lowest as for this we will require  $q^* > 1$  which violates the assumptions of the model.<sup>11</sup> Therefore, the firm will not opt for option 2. Intuitively, the firm will not choose the second option as the second stage is more important and the firm will not take the risk of assigning the important work to lower-quality skilled labours of  $B$  whose probability of making mistakes is higher. Therefore, the firm has to choose between option 1 and option 3. In this situation, if  $C(1^B, 2) < C(1,2)$  and  $C(1^B, 2) < C(1,2^B)$  then offshoring will be chosen.

$$C(1^B, 2) < C(1,2) \text{ implies } \frac{q^B + 1}{q^B} < \frac{2}{t_D}$$

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<sup>11</sup>For  $C(1,2^B)$  to be minimum we must have  $C(1,2^B) < C(1^B, 2) \Rightarrow \frac{w + w^B}{q q^{B^2}} < \frac{w^B + w}{q^B q^2}$ . Putting  $q = 1$  and  $w = 1$ ,  $\Rightarrow \frac{1 + q^B}{q^{B^2}} < \frac{q^B + 1}{q^B}$ , This implies  $q^B > 1$ .

$$\Rightarrow q^B > \frac{t_D}{2 - t_D} \quad (9)$$

$$\begin{aligned} \text{And } C(1^B, 2) < C(1, 2^B) &\Rightarrow \frac{q^B + 1}{q^B} < \frac{1 + q^B}{q^{B^2}} \\ &\Rightarrow q^B < 1 \end{aligned} \quad (10)$$

(9) and (10) provide conditions for which offshoring will be chosen. Similarly the conditions for domestic production are

$$\begin{aligned} C(1, 2) < C(1^B, 2) &\Rightarrow \frac{2}{t_D} < \frac{q^B + 1}{q^B} \\ &\Rightarrow q^B < \frac{t_D}{2 - t_D} \end{aligned} \quad (11)$$

$$\begin{aligned} \text{And, } C(1, 2) < C(1, 2^B) &\Rightarrow \frac{2}{t_D} < \frac{1 + q^B}{q^{B^2}} \\ &\Rightarrow t_D > \frac{2q^{B^2}}{1 + q^B} \end{aligned} \quad (12)$$

Plotting conditions (9)-(12) in figure 3:

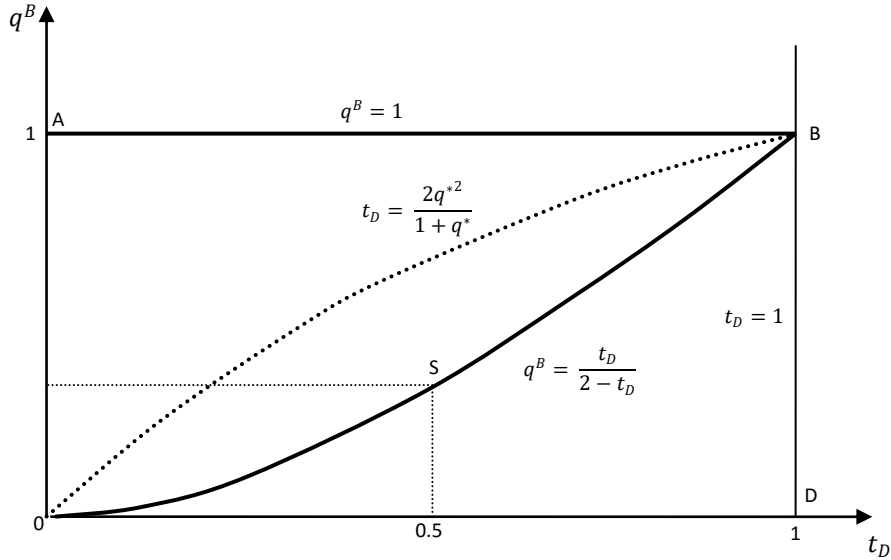


Figure 3: Offshoring condition when importance of stages of production varies

From figure 3, we see that condition (12) is satisfied for all values of  $q^B$  and  $t_D$  lying below the dotted curve  $OB$  and condition (11) is satisfied below the curve  $OSB$ . Therefore, if the values of  $q^B$  and  $t$  lies within the area  $OSBD$ , domestic production is preferred. On the other hand, if for a particular  $t_D$ , the value of  $q^B$  lies within the region  $OSBA$ , then the conditions for beneficial offshoring ((9) and (10)) are satisfied. Note that the condition for offshoring is same as in the previous section even when in this section the importance of stages varies. The difference that we see in presence of varying importance of stages is that the task with higher importance is not found economical to offshore even when there is gain in time. This corroborates Dei (2010) that only ‘*peripheral tasks are offshored.*’ Thus we propose,

**Proposition 3:** *With varying importance of production stages, the condition for offshoring does not change. However, the relatively important task is not offshored.* ■

#### 4 Presence of both high and low-quality skilled labours in country A

In this section, we consider country  $A$  to be endowed with skilled labours of both high ( $H$ ) and low ( $L$ ) quality while country  $B$  consists of only low-quality skilled labours. There are two sectors in both the countries,  $X$  and  $Y$ . One unit of  $X$  is produced using only one unit of low-quality labour within 12 hours. To simplify the model, we assume the low-quality skilled labours in country  $A$  and country  $B$  are homogeneous. Therefore, the production function of  $X$  in country  $A$  and  $B$  is

$$X = q_L$$

Assuming competitive markets, price is equal to unit cost. Therefore, for good  $X$

$$P_X = \frac{w_L}{q_L}$$

where  $w_L$  is the wage of  $L$  in both the countries. If  $X$  is numeraire then  $\frac{w_L}{q_L} = 1 \Rightarrow w_L = q_L$

Production of  $Y$ , on the other hand, is accomplished in two stages, each stage requiring 12 hours of work.  $Y$  can be produced using any kind of labour ( $H$  or  $L$ ) and accordingly output will be produced. The production functions is,



$$Y_\alpha = q_{\beta 1} q_{\beta 2} t \quad (13)$$

$t$  in equation (13) is the time factor, similar to the previous sections, with the range  $0 < t \leq 1$ .  $q_\beta$  ( $\beta = H, L;$ ) is the skill of labour where  $q_H$  is the skill of high-quality labour ( $H$ ) and  $q_L$  is the skill of low-quality labour ( $L$ ). We assume  $0 < q_L < q_H \leq 1$ . For simplicity, we assume  $q_H = 1$ . The subscripts 1 and 2 denote stages of production. As mentioned before, each stage of  $Y$  can be produced using any kind of labour. Thus,  $Y_\alpha$  ( $\alpha = 1, 2, 3$ ) is the output where  $Y_1$  is the output when both the stages are produced using  $H$ ,  $Y_2$  implies for one stage  $H$  ( $L$ ) is utilized and for other stage  $L$  ( $H$ ) is used; and  $Y_3$  implies both the stages use  $L$ . The level of output depends on the skill of the employed labour, higher quality labour yields higher output than lower quality labour. This implies  $Y_1 > Y_2 > Y_3$ . Also, in the autarkic situation  $t = t_D < 1$ . Now, the average cost of producing  $Y_1$  is

$$C(H, H) = \frac{2w}{q_H^2 t} = \frac{2}{t_D}$$

For brevity of the model we assume the wage of  $H$ ,  $w = 1$ . Similarly, average cost for producing  $Y_2$  and  $Y_3$  is, respectively,

$$C(L, H) = C(H, L) = \frac{w + w_L}{q_H q_L t} = \frac{q_L + 1}{q_L t_D}$$

$$C(L, L) = \frac{2w_L}{q_L^2 t} = \frac{2q_L}{q_L^2 t_D} = \frac{2}{t_D q_L}$$

Here,  $C(H, H) < C(H, L) < C(L, L)$  as  $q^B < 1$ .<sup>12</sup> Therefore, in autarky situation producing both the stages using  $H$  is the most economical strategy. Therefore, the output of  $Y$  in country  $A$  is  $Y_1$ .

With price equal to unit cost, we have,  $P_Y = \frac{2}{t_D}$ .

In country  $B$ , only low quality homogeneous skilled labours are present. Therefore, both stages of  $Y$  are produced using  $L$ . The production function of  $Y$  in country  $B$  is

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<sup>12</sup> We can also verify it using a numerical example. In our model,  $t_D = 0.5$ , and  $q_H = 1$ . Let  $q_L = 0.6$  then,  $C(H, H) = 4$ ;  $C(H, L) = 5.33$ ; and  $C(L, L) = 6.67$ . Thus  $C(H, H)$  is the lowest.

$$Y_3 = q_{L1}q_{L2}t_D$$

Now, equating cost and price,  $P_Y^B = \frac{2w_L}{q_L^2 t_D} = \frac{2q_L}{q_L^2 t_D} = \frac{2}{q_L t_D}$ , where  $P_Y^B$  is the price of  $Y$  in country  $B$ .

#### 4.1 Offshoring to country $B$

In the autarkic situation explained in the preceding section, it was observed that the cost incurred by  $Y$  producers by utilizing  $L$  either in one stage or both was not minimum. However, if one of the stages is offshored then there will be gain in time as  $t$  will become equal to  $t_o = 1$ , which can raise the output. Therefore, in this section we check whether it will be beneficial to offshore to country  $B$  that is located in a different time zone. So, if a firm in country  $A$  has the option to offshore one of the stages to country  $B$ , then it can employ  $H$  for one stage and  $L$  of country  $B$  for the other stage; or employ  $L$  of country  $A$  with  $L$  of country  $B$ . The firm's aim is to opt for the most economical option. Therefore, we compare the cost of the most economical autarkic-production option with the offshoring options mentioned above. The unit cost of each available option is

$$C(H, H) = \frac{2}{t_D}$$

$$C(H, L^B) = \frac{w + w^B}{t_o q_H q_L^B} = \frac{(1 + q_L^B)}{q_L^B} ; \text{ since } q_H = 1 \text{ and } t_o = 1$$

$$C(L, L^B) = \frac{2w^B}{t_o q_L^{B^2}} = \frac{2}{q_L^B}$$

Here,  $C(H, L^B) < C(L, L^B)$  as  $(1 + q_L^B) < 2$ . This means if offshoring takes place, domestic  $H$  will be used by  $Y$  and domestic  $L$  will be employed in sector  $X$ . Now we have to check whether

$$C(H, H) \leq C(H, L^B) \Rightarrow \frac{2}{t_D} \leq \frac{(1+q_L^B)}{q_L^B} \Rightarrow q_L^B \leq \frac{t_D}{2-t_D}.$$

The above condition suggests, if  $q_L^B < \frac{t_D}{2-t_D}$  both the stages will be produced in  $A$  using higher-quality skilled labours. On the other hand, if  $q_L^B > \frac{t_D}{2-t_D}$  offshoring one of the stage to country  $B$  will be beneficial. Note that the offshoring condition is similar to inequation (8), indicating that the offshoring condition does not change even when country  $A$  is endowed with both high and low-quality skilled labours. In the present case also, if  $t_D$  is low then offshoring to a country having lower-quality skilled workers becomes beneficial. If  $t_D$  is close to 1 then the quality of skilled labours of partner country should also be high to make offshoring beneficial

Moreover, it becomes evident that time plays a decisive role while deciding for offshoring. We observed that without the benefit of time, using  $L$  was not beneficial for the firm. However, with the opportunity to utilize the time efficiently by offshoring one of the production stages,  $L$  was preferred over  $H$ . Therefore, offshoring to a non-overlapping time zone is beneficial even when the quality of workers is relatively lower. Because the potential gain from saving time is more than the loss of employing lower quality skilled labours. Hence, we propose

***Proposition 4:*** *Y producers do not find it beneficial to use domestic low-quality skilled labours, but with the option of utilizing the time zone difference, foreign low-quality skilled labours are beneficially utilized to economize on production.* ■

## 5 Conclusion

In this paper, we aim to check whether there is matching of similar-skilled workers or dissimilar workers when there is an option to exploit the benefit of time zone difference between the partner countries. We frame a model following Dei (2010) where output is a supermodular function of quality of labours and timing of production. Firms have the option to produce using higher-skilled workers at high wage or offshore half of the production to another country located in a different time zone where labour cost is low and production saves time; however, the quality of workers is low. The paper derives a condition under which it is economical to offshore even when the partner country's workers are of relatively low quality. Thus, with the utilization of time zone difference, even if the production technology is supermodular, the firm's cost-minimizing behaviour will employ workers of dissimilar quality. However, if the quality level is

too low, offshoring does not take place as loss in output due to low-quality labour will be more than gain in output because of efficient utilization of time. We also observe that as domestic production utilizes time more efficiently, the skill requirement for offshoring increases. Next, we check the offshoring condition when the importance of each stage varies. We find that the condition for offshoring is same but the critical task is not offshored. Thirdly, we consider a situation where both high and low-quality labours are available domestically. Even in this situation, firms prefer to employ foreign low-quality workers in order to save time through time zone exploitation.

## Appendix

Offshoring to a country located in a non-overlapping time zone having low-quality skilled labour leads to a fall in productivity but time is efficiently utilized leading to a gain in output. In this section, we examine which situation, autarkic or offshoring, yields higher productivity. Productivity is measured as output per unit of input. Therefore, in autarky, productivity in sector  $Y$  is  $\frac{q^2 t_D}{2}$ . In offshoring case, productivity is  $\frac{q q^B}{2}$ .

Now, comparing productivity of the two situations,  $\frac{q^2 t_D}{2} \leq \frac{q q^B}{2}$

Putting  $q = 1$ , we get  $t_D \leq q^B$

Therefore, autarkic (offshoring) situation has higher productivity when  $t_D > q^B$  ( $t_D < q^B$ ) i.e., if time factor is higher (lower) than foreign labour quality index then autarkic (offshoring) situation is more productive.

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