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How to License a Transport Innovation

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Abstract

This paper identifies the optimal method to license an innovation that reduces transport cost in a duopoly model of spatial price discrimination. An inside innovator finds licensing by either a typical fixed fee or an output royalty unprofitable. Instead, we identify a fee based on distance as profitable. An outside innovator finds a fixed fee more profitable than either a royalty or a distance fee. It will license either one or both firms and when it does license both firms, it exploits a prisoner's dilemma between the duopolists in order to license an innovation that reduces their profit.

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1. Introduction

Economists have long studied how to license a patent for a process innovation that lowers production cost. Yet, this has rarely been cast in a spatial context and little attention has been paid to innovations that specifically lower transport cost. We change this by adopting a model of spatial price discrimination and by determining how to charge for an innovation that lowers transport costs. Under spatial price discrimination, transport cost is an essential element in the ability of firms to earn profit as they charge a price that includes delivery of the product. A firm that reduces its transport cost gains both customers and profit. As a consequence, there exists a need to understand how to license a transport innovation.

In this paper, we first model a duopoly in which one firm innovates to distribute more cheaply and contemplates licensing this innovation to its rival. We show that under spatial price discrimination both traditional choices, a fixed fee or a royalty, are *unprofitable*. The innovation will simply not be shared. We show that when the innovator charges a license fee based on distance, the innovation will be licensed. We present an initially counter-intuitive result that the innovator will be able to charge a distance fee that exceeds the cost reduction of the innovation. Yet, we emphasize that this makes sense as even fees above the cost reduction allow the rival to earn additional profit because of an accommodating location choice of the innovator. We describe the licensing equilibrium showing that it increases social welfare relative to not licensing but that the licensing fee is too large to maximize social welfare.

We next contrast this choice of the distance fee with an outsider who innovates and decides among the same three licensing methods. Here the innovator earns profit from any method of licensing but earns the most by charging a fixed fee. Depending upon the size of the innovation (the extent to which it lowers transport costs), the innovator may find it profitable to license to one or both duopolists. We isolate the unique role played by a prisoner's dilemma. If they could act in concert, the duopolists would prefer not to accept the innovation as reduced transport cost reduces the profitability of spatial price discrimination. It is the ability of the outside innovator to craft a dominate strategy that results in both duopolists purchasing the license, and so earning less profit, and in an improvement in social welfare.

Our investigation is timely as improving distribution and lowering transport cost commands enormous attention from businesses. Recently consumer firms Unilever and Evian North American brought their transportation in house and reformed their transport management in efforts to reduce costs (Unilever, 2011 and Harps, 2006). More generally, innovations that reduce transport cost include, but are not limited to, efficient route planning and load tendering, advanced transit management and tracking, improvements in actual transit technology (be it by any mode or modes) and reducing time and costs associated with loading/unloading (Stefansson and Lumsden, 2009).

When transportation and distribution costs comprise a substantial share of overall costs, economists know there are strong incentives to engage in spatial price discrimination. Thisse and Vives (1988) show that discriminatory pricing is the preferred alternative when firms are able to adopt it and Greenhut (1981) identifies it as "nearly ubiquitous" among actual markets in which the products have substantial freight costs. Thus, rather than allow customers to arrange their own delivery, the price quoted for goods includes delivery. This internalizes transport cost for the firm generating incentives to lower that cost through innovation. As we will show, this brings to the forefront a licensing strategy that explicitly includes distance. Such licensing has received little attention by economists but there exist famous historical examples. Congressional hearings describe how in 1852 Thomas Sayles licensed the patent of double-acting brakes to many US railroad companies with a distance fee of $10 per mile (US Senate, 1878). Earlier in 1843

Charles Wheatstone licensed the patent for the five-needle telegraph also on a per mile basis. The royalty was £20 per mile for any first 10 miles laid with the per mile charge declining for additional increments (Bowers, 2001).

Outside the spatial context, economists focusing on process innovations often compare fixed fee licenses or royalty licenses. In basic Cournot competition, the fixed fee license is typically superior to per unit royalty licensing when the innovator is not producing the product (Kamien and Tauman, 1986; Katz and Shapiro, 1986; Kamien et al., 1992). Yet, if the innovating firm also produces the product, a royalty license will be chosen because it provides both licensing fees and a competitive advantage (Wang, 1998; Kamien and Tauman, 2002).

In the spatial framework, nearly all previous research has been set in Hotelling type models of price competition. Taking location choices as exogenous both Poddar and Sinha (2004) and Kabiraj and Lee (2011) emphasize that a royalty will be chosen to license a production cost reducing innovation. Allowing location to be endogenous but on a circle, Caballero-Sanz et al (2002) show an outside innovator will adopt a royalty rather than an auction or a fixed fee. Matsumura et al. (2009) assume a royalty will be the licensing method by an inside innovator and show the resulting locations on a line will be at the end points to maximize the product differentiation. Colombo (2014) imposes separate locations for two firms that would otherwise colocate and shows that royalty licensing is more profitable than fixed fee licensing in quantity competition where each firm sells at every location and the quantity of sales differ by location. None of these studies consider spatial price discrimination or a transport cost reducing innovation. Heywood and Ye (2010) do adopt spatial price discrimination but focus on a process innovation that lowers production costs and so they assume transport cost is constant and unaffected by the innovation.

We uniquely combine spatial price discrimination and an innovation that lowers transportation cost to provide a series of new insights. The next section sets-up the model for an inside innovator and shows that only the fee dependent on distance is profitable. The third section illustrates the equilibrium showing the consequences for social welfare. The fourth section examines the outside innovator and highlights the role of the fixed fee and the ability to exploit a prisoner's dilemma to encourage firms to purchase a license that lowers their profitability. In the final section we summarize and suggest future avenues of research.

2. An Inside Innovator

The market is normalized to a unit line segment and consumers are uniformly distributed along the market. Each consumer can buy one unit with reservation price Γ. We assume that Γ is everywhere above the delivered cost of the two competing firms. The transport costs per unit of distance for the firms are t_1 and t_2 and the locations are L_1 and L_2 where $L_1 \leq L_2$. We arbitrarily set a constant per unit production cost to zero and imagine that Firm 1 creates a new technology that lowers its transport cost by *c*, such that $t_1 = t - c$, $t_2 = t$, and $c < t$.

The game consists of three stages. In the first stage, Firm 1 decides whether or not to license to Firm 2 and if so, whether to do so by means of a fixed fee *F*, an output royalty *r* or a per unit of distance fee, d. Given the licensing decision made in the first stage, both firms simultaneously choose their locations in the second stage. The spatial price schedule is announced in the third stage.

The model is solved by backward induction. We illustrate by first examining the case of no licensing. The price schedule under discrimination is the outer envelope of the rivals' delivered costs as shown in Figure 1. For any consumer located at *x* the price is $p(x, L_1, L_2) =$

$\max\{t(L_2 - x), (t-c)(x - L_1)\}$. Customers buy from the firm with lower delivered cost and so the consumer located at $x^* = \frac{-L_1 t + L_1 c - tL_2}{-2t+c}$ is indifferent between firms.[1] The general expressions for profits (before paying or receiving licensing fees) are

$$\pi_1 = \int_0^{L_1} t_2(L_2 - x) - t_1(L_1 - x)dx + \int_{L_1}^{x^*} t_2(L_2 - x) - t_1(x - L_1)dx \qquad (1)$$

$$\pi_2 = \int_{x^*}^{L_2} t_1(x - L_1) - t_2(L_2 - x)dx + \int_{L_2}^{1} t_1(x - L_1) - t_2(x - L_2)dx \qquad (2)$$

as identified in Figure 1.

In the second stage, each firm maximizes its own profit with respect to its location given $t_1 = t - c$, $t_2 = t$, and x^*. Solving the resulting best response functions simultaneously yields $L_1^{NL} = \frac{t}{4t-2c}$ and $L_2^{NL} = \frac{3t-c}{4t-2c}$. Returning these to (1) and (2) yields

$$\pi_1^{NL} = \frac{t^2(3t-c)}{4(2t-c)^2} \qquad (3)$$

$$\pi_2^{NL} = \frac{7tc^2 - 8ct^2 + 3t^3 - 2c^3}{4(2t-c)^2} \qquad (4)$$

Note that when c=0 (the firms have the same transport cost), the firms locate at the quartiles, $L_1 = \frac{1}{4}$ and $L_2 = \frac{3}{4}$ (Hurter and Lederer, 1985) but move increasingly right as c increases. We now consider the three possible licensing schemes and ultimately compare π_1^{NL} and Firm 1's profit under the alternative licensing schemes to determine the final equilibrium.

2.1 Licensing with a Fixed Fee

If Firm 1 licenses with fixed fee F, $t_2 = t - c$. The resulting price schedule becomes $p(x, L_1, L_2) = \max\{(t-c)(L_2 - x), (t-c)(x - L_1)\}$. The total profits are $\pi_1^F = \pi_1 + F$ and

$\pi_2^F = \pi_2 - F$, where $\pi_1$and π_2 are (1) and (2) after recognizing that $t_1 = t_2 = t - c$ and $x^* = \frac{L_1+L_2}{2}$.

Firm 1 and Firm 2 have identical transport costs, locate at the quartiles and $\pi_1^F = \frac{3}{16}(t-c) + F$ and $\pi_2^F = \frac{3}{16}(t-c) - F$. Firm 1 charges the largest fixed fee acceptable to Firm 2 by making it indifferent to licensing: $F = \frac{3}{16}(t-c) - \pi_2^{NL} = \frac{c(8t^2-13tc+5c^2)}{16(2t-c)^2}$ and so

$$\pi_1^F = \frac{6t^3-8ct^2+tc^2+c^3}{8(2t-c)^2} \tag{5}$$

2.2 Licensing with a Per Unit of Output Royalty

Firm 1 charges a royalty *r* for each unit sold regardless of distance shipped. Now $t_2 = t - c$ but the price schedule includes *r*: $p(x, L_1, L_2) = \max\{r + (t-c)(L_2 - x), (t-c)(x - L_1)\}$. The resulting profits are $\pi_1^R = \pi_1 + r$ and $\pi_2^R = \pi_2 - r(1 - x^*)$ where $t_1 = t_2 = t - c$ and $x^* = \frac{L_1 t - L_1 c + r + tL_2 - cL_2}{2(t-c)}$. The expression for the Firm 2's profit shows it paying the royalty on each unit it sells but that Firm1 includes *r* on each unit sold by either firm. Obviously, it receives *r* as the payment from Firm 2 on the units Firm 2 sells but the fact that Firm 2's delivered cost is uniformly increased by *r* means that it implicitly receives *r* on all of its own units sold as well.

In the second stage the locations again follow from each firm maximizes profit with respect to location and simultaneously solving the resulting best response functions. These locations are functions of *t*, *c* and *r* and when returned to the profit expressions yield $\pi_1^R = \frac{12c^2-76rc-24tc+76rt-13r^2+12t^2}{64(t-c)}$ and $\pi_2^R = \frac{3(4c^2+12rc-8tc-12rt+9r^2+4t^2)}{64(t-c)}$. Firm 1 maximizes π_1^R with respect to *r* subject to the constraint that $\pi_2^R = \pi_2^{NL}$. The constraint ensures that the rival will accept the license and it is easy to show that $\frac{\partial \pi_1^R}{\partial r} > 0$ for *r* less than that implied by the constraint.[2] The solution implied by the constraint is then $r = \frac{2\left(-3c+6t-2\sqrt{6c^2-15tc+9t^2}\right)(t-c)}{9(2t-c)}$ which generates equilibrium locations $L_1^R = \frac{6c-12t+\sqrt{6c^2-15tc+9t^2}}{18(-2t+c)}$ and $L_2^R = \frac{6c-12t+\sqrt{6c^2-15tc+9t^2}}{6(-2t+c)}$. These locations imply that

$$\pi_1^R = \frac{345t^3+389tc^2-664t^2c-70c^3+(132tc-44c^2-88t^2)\sqrt{6c^2-15tc+9t^2}}{108(2t-c)^2} \tag{6}$$

2.3 Licensing with a Per Unit of Distance Fee

Firm 1 licenses with a fixed rate of *d* per unit of distance such that $t_2 = t - c + d$. The equilibrium pricing schedule is $p(x, L_1, L_2) = \max\{(t-c+d)(L_2 - x), (t-c)(x - L_1)\}$. Substituting $t_1 = t - c$, $t_2 = t - c + d$, and $x^* = \frac{-L_1t+L_1c-L_2t+L_2c-L_2d}{-2t+2c-d}$ into (1) and (2) yields $\pi_1^D = \pi_1 + \int_{x^*}^{L_2} d(L_2 - x)dx + \int_{L_2}^{1} d(x - L_2)dx$ and $\pi_2^D = \pi_2$.

In the second stage the locations again follow from each firm maximizing profit with respect to location and simultaneously solving the best response functions: $L_1^D = \frac{2c^2-2cd-4tc+2t^2+2td+d^2}{8c^2-7cd-16tc+2d^2+8t^2+7td}$ and $L_2^D = \frac{2(3c^2-3cd-6tc+3t^2+3td+d^2)}{8c^2-7cd-16tc+2d^2+8t^2+7td}$. These values are returned to the profit expressions to yield π_1^D and π_2^D as shown in the appendix. Firm 1 now maximizes π_1^D with respect to *d* subject to the constraint that $\pi_2^D = \pi_2^{NL}$. The constraint again insures that the rival will accept the license and it can be checked that $\frac{\partial \pi_1^D}{\partial d} > 0$ for all values of *d*. Thus, the constraint binds and has a single positive real root, $d'(c,t)$, that can be solved but is a messy higher order function of *c* and *t* (although available upon request). Critically, the optimal value *d* that is always above *c*. We show this by normalizing *t*=1 so that *c* becomes the share of the transport cost eliminated by innovation and *d* becomes the share of transport cost being charged as a distance fee. In this case, $d'(c, t = 1) - c = 0$ only when *c* itself equals zero and is otherwise positive.[3] For example when the innovation reduces transport cost to half of its previous size, *c*=0.5, the profit maximizing distance fee is d'=0.657.

We will show that the optimal choice is to license with the distance fee *d* but first we explain the effect of *d* on locations and why the optimal *d* is greater than *c*. We do this in a first proposition that highlights the accommodating response of the innovator to a large distance fee.

Proposition 1: i) $\frac{\partial L_1^D}{\partial d} > 0$ and $\frac{\partial L_2^D}{\partial d} > 0$; ii) if *d*=*c*, $L_1^D < L_1^{NL}$ and $L_2^D < L_2^{NL}$and $\pi_2^D - \pi_2^{NL} > 0$.

Proof: i) $\frac{\partial L_1^D}{\partial d} = \frac{(t-c)(3d^2+8d(t-c)+2(t-c)^2)}{(-16tc-7cd+2d^2+8c^2+8t^2+7td)^2} > 0;$

$\frac{\partial L_2^D}{\partial d} = \frac{2(t-c)(d^2+4d(t-c)+3(t-c)^2)}{(-16tc-7cd+2d^2+8c^2+8t^2+7td)^2} > 0.$

ii)$L_1^D(d = c) - L_1^{NL} = \frac{c(c-t)(2c-3t)}{2(-2t+c)(3(t-c)^2+3t(t-c)+2t^2)} < 0;$ $L_2^D(d = c) - L_2^{NL} =$

$\frac{c(c-t)^2}{2(-2t+c)(3(t-c)^2+3t(t-c)+2t^2)} < 0;$ $\pi_2^D(d = c) - \pi_2^{NL} = \frac{c(-3t+2c)(-t+c)^3(5(t-c)^2+7t(t-c)+4t^2)}{4(-9tc+3c^2+8t^2)^2(-2t+c)^2} > 0.$

Given that Firm 2 has the new transport technology, as *d* increases Firm 2 has increasingly higher transport costs than Firm 1 and, as a consequence, the optimal locations of both firms move right. Critically, when *d* = *c,* each firm has identical transport costs to those without licensing but the locations differ from those without licensing. Firm 1 locates less aggressively, closer to the left as shown by ii), as it earns licensing revenue that grows with the market share of Firm 2. The more accommodating location of Firm 1 implies that when *d* = *c*, Firm 2 also moves left and so earns profits greater than those without the new technology despite having the same transport costs. Thus, Firm 1 can actually increase the value of *d* above *c* moving both firms right until Firm 2 earns profit identical to its no licensing case.[4] This ability of Firm 1 to dramatically increase licensing revenue through an accommodating location sets up the equilibrium in the final stage.

2.4 The Equilibrium

The choice of licensing scheme follows from comparing the profit of Firm 1 in the four cases outlined.

Proposition 2: i) Fixed fee and royalty licensing are never profitable. ii) The distance fee is profitable.

Proof:

i) Subtracting (3) from (5) yields $\pi_1^F - \pi_1^{NL} = -\frac{c(c+3t)}{8(2t-c)} < 0$. Subtracting (3) from (6) yields

$\pi_1^R - \pi_1^{NL} = -\frac{70c^3-389tc^2+637t^2c-264t^3+(44c^2-132tc+88t^2)\sqrt{6c^2-15tc+9t^2}}{108(2t-c)^2} < 0.$

ii) $\pi_1^D(d=c) - \pi_1^{NL} = \frac{c(c-t)^3\left(6(c^3-t^3)-9tc^2-25t(t-c)^2-17(t-c)t^2\right)}{4(8t^2+3c^2-9tc)^2(2t-c)^2} > 0$; $\frac{\partial \pi_1^D}{\partial d} =$

$\frac{8d^6+84(t-c)d^5+374(t-c)^2d^4+901(t-c)^3d^3+1272(t-c)^4d^2+1016d(t-c)^5+368(t-c)^6}{2(2d^2+7d(t-c)+8(t-c)^2)^3} > 0$. As $d' > c$ (from above), $\pi_1^D(d=d') - \pi_1^{NL} > 0$.

The best fixed fee is not sufficient to outweigh the disadvantage of facing a rival with equal transport costs. Similarly, the royalties earned per unit of output and the resulting increased production cost of Firm 2 do not outweigh the disadvantage of facing a rival with equal transport costs. Only when Firm 1 can not only maintain but expand its transport cost advantage will it make sense to license and the licensing scheme that can accomplish this is dependent upon distance.

3. Illustrating the Consequences of the Licensing Equilibrium

We now illustrate the equilibrium that uses the distance fee. We first present a simulation of the locations for different size innovations and contrast those with the locations that happen without licensing. We then show that the equilibrium with licensing improves social welfare relative to that without licensing but that it generates a licensing fee that is too large to maximize social welfare.

To get a sense of the impact of the distance fee licensing on firms' locations we consider a series of cost reductions associated with innovation, $c = 0.1t, \ldots, 0.9t$. For each of the nine values from a 10 percent reduction in costs to a 90 percent reduction in costs, we calculate the equilibrium locations associated with no licensing and with the licensing equilibrium we have derived. These are presented in Table 1 and illustrate that the two firms move to the right in either equilibrium as c increases. Critically, for any given value of c, the licensee locates further to the right under the licensing equilibrium than in the case of no licensing. At the same time, the innovator locates further to the left under the licensing equilibrium than under the case of no licensing. Thus, the availability of licensing pushes the firms toward the corners. The movement right by the licensee is generally far smaller than the accommodating movement of the innovator left.

The consequence of licensing on social welfare depends, in part, on these movements. Any movement toward symmetry improves welfare as does the fact that fewer real resources are used to transport the goods of the licensee.

Now, we compare the social welfare with and without licensing. The social welfare (SW) follows as the difference between total willingness to pay and the real transport cost (TC): $SW =$

$\Gamma - TC$. The transport cost under no licensing is: $TC^{NL} = \frac{1}{2}(t-c)(L_1)^2 + \frac{1}{2}(t-c)(x^* - L_1)^2 + \frac{1}{2}t(L_2 - x^*)^2 + \frac{1}{2}t(1-L_2)^2$ where $x^* = \frac{-L_1 t + L_1 c - tL_2}{-2t+c}$. The transport cost under distance fee licensing is: $TC^D = \frac{1}{2}(t-c)(L_1)^2 + \frac{1}{2}(t-c)(x^* - L_1)^2 + \frac{1}{2}(t-c)(L_2 - x^*)^2 + \frac{1}{2}(t-c)(1-L_2)^2$. Note that the real transport cost per unit for Firm 2 does not include the licensing transfer to Firm 1 yet that transfer influences the location of the indifferent consumer so that $x^* = \frac{-L_1 t + L_1 c - L_2 t + L_2 c - L_2 d}{-2t+2c-d}$. The social welfare under no licensing is: $SW^{NL} = \Gamma - \frac{t(t-c)}{4(2t-c)}$ but the social welfare under distance fee licensing remains a higher order function of *c* and *t*. By again normalizing *t*=1, both social welfare functions can be easily graphed over the entire range of *c*. These are shown in Figure 2 and make clear that $SW^{d'} - SW^{NL} > 0$ for all $0 < c < t$. Licensing improves welfare.

While it is clear that a governmental authority concerned with welfare should allow licensing with a distance fee, it may wish to control the size of that fee. On the one hand, a fee of zero would result in efficient locations at the quartiles and minimize the real resources spent on transportation.[5] Yet, the obvious problem with setting such a fee is that it lowers the profit of firm 1 and so licensing will not happen. Thus, we explore a governmentally set fee that maximizes the increase in welfare associated with licensing subject to the constraint that the innovator has an incentive to license.

We have already shown that the profit of Firm 1 increases in *d* and it can be shown that social welfare decreases in *d*. Thus, the welfare maximizing fee is that which makes Firm 1 indifferent to licensing and this fee is lower than the equilibrium level. When one solves the implied constraint that π_1^D in the appendix equals π_1^{NL} it yields a higher order polynomial root that can again be easily graphed. Figure 3 show the constrained optimum, d^*, and shows $d^* <$

d' and while $d' > c$, $d^* < c$ for all $0 < c < t$. The locations associated with the socially optimal fee are illustrated in Table 1. They show that both firms locate to the left of either the no-licensing case or the licensing equilibrium. The smaller fee promotes the leftward accommodation of the innovator but does not allow it to be fully exploited. Indeed, it is straightforward to see that the profitability of the rival increases as a result of the license even as that of innovator remains the same as without licensing. The total transport costs are illustrated in Table 2 showing the welfare maximizing costs to be lowest but closer to those in the licensing equilibrium than the costs in that equilibrium are to those in the case without licensing.

We recognize that we have illustrated only the solution to the static problem of how to a government should price an existing innovation. We have not modeled the R&D process and a governmental authority concerned with providing optimal dynamic incentives for innovation might adopt an alternative fee. This would presumably be higher and provide a licensing return to the innovator raising the traditional issues of dynamic vs. static efficiency common in studying patents.

4. An Outside Innovator

We now consider a transport cost-reducing innovation from a market outsider. The basics of the framework remain identical but now without licensing $t_1 = t_2 = t$ and with licensing $t_i = t - c$. The game again consists of three stages. In the first stage, the outsider now decides whether to license and if so, by which method and to how many firms. We consider the same three potential licensing fees. In the second stage the firms decide whether or not to accept the license and then simultaneously locate. In the third stage, the price schedule is announced.

We again solve by backward induction and first review the no licensing case. The consumer located at *x* is charged $p(x, L_1, L_2) = \max\{t(L_2 - x), t(x - L_1)\}$. Firm profits are $\pi_1^{NL} = \pi_1$ and $\pi_2^{NL} = \pi_2$ where π_1 and π_2 are (1) and (2) after substituting $t_1 = t_2 = t$ and $x^* = \frac{L_1+L_2}{2}$. With identical transport cost per unit of distance, firms locate at the quartiles and

$$\pi_1^{NL} = \pi_2^{NL} = \frac{3}{16}t \tag{7}$$

Obviously, the outside innovator earns no profit in this case, L=0 (where L denotes the outside innovator's licensing revenue).

4.1 Licensing with a Fixed Fee

If the outside innovator licenses to both firms with a fixed fee F, L=2F and $t_1 = t_2 = t - c$. The price schedule is $p(x, L_1, L_2) = \max\{(t - c)(L_2 - x), (t - c)(x - L_1)\}$. The total profits are $\pi_1^F = \pi_1 - F$ and $\pi_2^F = \pi_2 - F$ where π_1 and π_2 are (1) and (2) with $t_1 = t_2 = t - c$ and $x^* = \frac{L_1+L_2}{2}$. The firms locate at quartiles and $\pi_1^F = \pi_2^F = \frac{3}{16}(t - c) - F$. Importantly, if the firms were to cooperatively decide, they would not accept the license as both the fixed fee and the lower transport cost reduce profits. However, in a non-cooperative equilibrium, there exists the fear that the rival will accept the innovation if one firm unilaterally declines. We describe the resulting prisoner's dilemma.

Imagine only Firm 1 purchases the license, then $\pi_1^{F1} = \pi_1 - F1$ and $\pi_2^{F1} = \pi_2$ where $t_1 = t - c$, $t_2 = t$, and $x^* = \frac{-L_1t+L_1c-tL_2}{-2t+c}$. In the second stage each firm maximizes its profit with respect to its location and solving the resulting best response functions simultaneously yields the equilibrium locations. These locations yield $\pi_1^{F1} = \frac{t^2(3t-c)}{4(2t-c)^2} - F1$ and $\pi_2^{F1} = \frac{7tc^2-8ct^2+3t^3-2c^3}{4(2t-c)^2}$.

The fixed fee *F1* makes Firm 1 indifferent about buying the innovation and is determined by subtracting (7) from $\frac{t^2(3t-c)}{4(2t-c)^2}$. Thus

$$L\text{=}F1 = \frac{tc(8t-3c)}{16(2t-c)^2} \qquad (8)$$

Thus, for any fixed fee less than or equal to *F1* Firm 1 purchases the license when its rival doesn't. If Firm1, indeed, purchases the license, Firm 2 could be better off by also purchasing the license. The profit for each firm if both firms purchase the license is $\frac{3}{16}(t-c) - F$ which can be compared to π_2^{F1}. Firm 2 thus purchases the license whenever the fixed fee is less than or equal to $\frac{3}{16}(t-c) - \pi_2^{F1} = \frac{c(8t^2-13tc+5c^2)}{16(2t-c)^2} = F^*$. It can be shown that $F^* < F1$ and thus it is the largest fee that will make purchasing the license a dominant strategy for each firm. The outsider's licensing revenue is

$$L = 2F^* = \frac{c(8t^2-13tc+5c^2)}{8(2t-c)^2} \qquad (9)$$

By comparing the licensing revenue in (8) to that in (9), the outside innovator decides whether to license to one firm or two firms.

Proposition 3: The outside innovator licenses by a fixed fee to both firms when $0 < c < .427t$ and to only one firm when $.427t < c < t$.

Proof: Subtracting (8) from (9) yields $\frac{8t^2c-23tc^2+10c^3}{16(2t-c)^2}$ which when set equal to zero and solved yields c=.427t and the sign can be checked either side of this critical value.

When two licenses are sold, equilibrium locations remain at the quartiles. Moreover, because of the need to make licensing a dominant strategy for both firms, the profit of each firm increases as a result of licensing. If only a single firm is licensed, the full value of the cost reduction is extracted by the innovator. Which strategy is chosen depends on the relative size of *c* to *t*. When *c* is small relative to *t*, a single firm with access to the technology gains relatively little market share and as a consequence it less profitable to sell only one license. When the cost reduction is large, extracting the full value can be more profitable as the single licensed firm gains substantial market share.

4.2 Licensing with an Output Royalty

If the outside innovator licenses to both Firm 1 and Firm 2 with an output royalty r for each unit sold then $t_1 = t_2 = t - c$ and the price schedule is $p(x, L_1, L_2) = \max\{r + (t - c)(L_2 - x),\ r + (t - c)(x - L_1)\}$. As both firms pay r per unit, the royalty influences neither locations nor the resulting profits. Thus, $\pi_1^r = \pi_1$ and $\pi_2^r = \pi_2$, where π_1 and π_2 are (1) and (2) with $t_1 = t_2 = t - c$ and $x^* = \frac{L_1+L_2}{2}$. As Γ continues to exceed the delivered costs by assumption, *L*= r and $\pi_1^r = \pi_2^r = \frac{3}{16}(t - c)$. While the firms no longer lose profit to a fixed fee, they continue to earn less than without the technology and the prisoner's dilemma remains.

If only Firm 1 purchases the patent, $t_1 = t - c$, $t_2 = t$,and $L = (r1)x^*$. The price schedule becomes $p(x, L_1, L_2) = \max\{t(L_2 - x), (r1) + (t - c)(x - L_1)\}$. Firm profits are $\pi_1^{r1} = \pi_1 - (r1)x^*$and $\pi_2^{r1} = \pi_2 + (r1)(1 - x^*)$, where π_1 and π_2 are (1) and (2) with $t_1 = t - c$, $t_2 = t$, and $x^* = \frac{tL_1+tL_2-(r1)-cL_1}{2t-c}$. In the second stage, each firm maximizes its profit over its own location and simultaneously solving the resulting best response functions yields equilibrium locations. Returning these locations to outside innovator's licensing revenue and firms' profits yields $L = \frac{(r1)(t-2(r1))}{(2t-c)}$ and

$$\pi_1^{r1} = \frac{(2(r1)-t)^2(3t-c)}{4(2t-c)^2} \tag{10}$$

$$\pi_2^{r1} = \frac{(t+2(r1)-c)^2(3t-2c)}{4(2t-c)^2} \tag{11}$$

Firm 1 gains the market advantage of lower transport cost but must pay the royalty. The outsider maximizes royalty income and it can be shown that $\frac{\partial L}{\partial r1} > 0$ for all royalties that would induce Firm 1 to purchase the license. Thus, the outside innovator chooses *r1* so that (10) equals the profit without licensing in (7): *r1*=$\frac{-6t^2+2tc+\sqrt{36t^4-48t^3c+21t^2c^2-3c^3t}}{4(c-3t)}$. The resulting licensing revenue is

$$L=(r1)x^* = \frac{t(-3c^2+12tc-12t^2+2\sqrt{3t(3t-c)(2t-c)^2})}{8(3t-c)(2t-c)} \tag{12}$$

If Firm 1 purchases the license, Firm 2 might also be better off purchasing the license. When two licenses are sold, the profit of each firm is $\frac{3}{16}(t-c)$ which equals (11) when

$$r^* = \frac{-4c^2+10tc-6t^2+\sqrt{6c^4-39tc^3+93c^2t^2-96t^3c+36t^4}}{4(3t-2c)} \tag{13}$$

It can be shown r^*<*r1* and thus both firms will purchase the license as a dominant strategy for any royalty less than or equal to r^*. Thus, when selling to two firms *L*=r^*.

The optimal number of firms to be licensed can be determined.

Proposition 4: The outside innovator licenses by an output royalty to both firms when $0 < c < .847t$ and to only one firm when $.847t < c < t$.

Proof: Subtracting (12) from (13) yields

$$\frac{54tc^3-8c^4-127t^2c^2+120t^3c-36t^4-\left(10ct-2c^2-12t^2\right)\sqrt{3(2c^2-5ct+3t^2)(2t-c)^2}+(4tc-6t^2)\sqrt{3t(3t-c)(2t-c)^2}}{8(3t-2c)(3t-c)(2t-c)}$$

which when set equal to zero and solved yields c=.847t and the sign can be checked either side of this critical value.

Again, if both firms are licensed the locations remain at the quartiles. The outside innovator collects the smaller royalty but for all units sold in the market. With one license, it collects the larger royalty but only on the units of one firm. The share of the market for that one firm is larger when c is larger. Thus, only for large values of c, will the higher royalty fee cause the outsider to sell only to one firm. This largely mimics the result with the fixed fee.

4.3 Licensing with a Per Unit of Distance Fee

If the outside innovator licenses to both firms with a distance fee d, then $t_1 = t_2 = t - c + d$. The price schedule is $p(x, L_1, L_2) = \max\{(t - c + d)(L_2 - x), (t - c + d)(x - L_1)\}$. Substituting $t_1 = t_2 = t - c + d$ and $x^* = \frac{L_1+L_2}{2}$ into (1) and (2) yields $\pi_1^d = \pi_1$ and $\pi_2^d = \pi_2$. The outside innovator's total income is $L= \int_0^{L_1} d(L_1 - x)dx + \int_{L_1}^{x^*} d(x - L_1)dx + \int_{x^*}^{L_2} d(L_2 - x)dx + \int_{L_2}^{1} d(x - L_2)dx$. Each firm earns $\pi_1^d = \pi_2^d = \frac{3}{16}(t - c + d)$.

If only Firm 1 purchases the patent then $t_1 = t - c + d1$ and $t_2 = t$. The price schedule is $p(x, L_1, L_2) = \max\{t(L_2 - x), (t - c + d1)(x - L_1)\}$. Firms' profits are $\pi_1^{d1} = \pi_1$ and $\pi_2^{d1} = \pi_2$ where π_1 and π_2 are (1) and (2) with $t_1 = t - c + d1$, $t_2 = t$, and $x^* = \frac{-L_1t+L_1c-L_1(d1)-tL_2}{-2t+c-(d1)}$.

The outside innovator's revenue is $L = \int_0^{L_1}(d1)(L_1 - x)dx + \int_{L_1}^{x^*}(d1)(x - L_1)dx$. In stage 2 each firm maximizes its profit with respect to its own location and simultaneously solving the resulting best response functions yields equilibrium locations. Returning the equilibrium locations to the outside innovator's licensing revenue and each firm's profit yields $L = \frac{(d1)t^2}{4(2t-c+(d1))^2}$ and

$$\pi_1^{d1} = \frac{t^2(-c+(d1)+3t)}{4(2t-c+(d1))^2} \tag{14}$$

$$\pi_2^{d1} = \frac{(3t-2c+2(d1))(t-c+(d1))^2}{4(2t-c+(d1))^2} \tag{15}$$

The outside innovator maximizes L with respect to $d1$ subject to the constraint that (14) is larger than or equal to (7). It can be checked that $\frac{\partial L}{\partial d1} > 0$ for values of $d1$ that meet the constraint. Thus, $d1$=c and L=$\frac{1}{16}c$.

Thus, for any distance fee less than or equal to $d1$ Firm 1 will purchase the license when its rival doesn't. If Firm 1 has the innovation, Firm 2 could be better off by also purchasing the license. The maximum amount the second firm will pay is given by setting $\pi_2^d = \frac{3}{16}(t - c + d)$ equal to (15) and solving. Thus, $d^* = c$ and the outside innovator will charge c no matter how many firms are licensed and so will license both firms. With two licenses sold, the licensing revenue is

$$L = \frac{1}{8}c \tag{16}$$

In this case there is no tradeoff between a higher licensing fee and the number of firms licensed.

4.4 The Equilibrium

The final equilibrium reflects the outsider's choice of licensing scheme.

Proposition 5: For an outside innovator all three forms of licensing are profitable but charging a fixed fee is the most profitable.

Proof: A piecewise comparison of L across all values of c from 0 to t for each licensing scheme shows the fixed fee dominates. This comparison is presented in Figure 4.

The optimal distance fee is charged to both firms and as a consequence, the licensing revenue is simply linear in c from (16). For either a fixed fee or the royalty a single firm is licensed with large enough c. The inflection points from propositions (3) and (4) are illustrated in Figure 4. Because paying a fixed fee gives the single licensed firm a bigger cost advantage and market share, the inflection comes at smaller c than for the royalty. As a consequence of this larger advantage, the value of the license is greatest to a single firm when paying a fixed fee making it the optimal single license for the outsider. Importantly, this large advantage for the single licensed firm means the greatest competitive harm to the excluded rival. As a consequence, the excluded rival will pay the most to receive a second license under the fixed fee. Thus, regardless of whether licensing to one or two firms the fixed fee will be chosen

As in the case of an insider innovating, licensing improves social welfare. Social welfare remains the difference between total willingness to pay and real transport cost. With two licenses sold, the reduction in unit transport cost improves social welfare without changing firms' locations relative to the no licensing case. Moreover, these locations are first best. When only one firm is licensed the fact that asymmetric locations emerge is outweighed by the fact that transport costs are lower for most of the market.[6] Yet, the locations are not first best and a social planner would prefer licensing to both firms.

5. Conclusion

This paper is unique in studying the licensing of a transport cost-reducing innovation. We recognize that such an innovation can be critical under spatial price discrimination in which the consumer pays a delivered price. While the Cournot quantity model argues that royalties are preferable to fixed fees for an insider, we show that both of these fee structures are impossible for the innovation we study. Neither generates profit and it remains better for the innovator to simply enjoy lower transport cost. We show that the per unit distance fee provides the innovator with both licensing revenue and a superior competitive position. This combination proves profitable and the distance fee will be adopted by the innovator.

When innovator is outside the market, we show that the fixed fee license always generates the highest licensing revenue. This result in some ways mimics that from simply Cournot competition. Like that case the innovator can extract the most revenue but the mechanism differs. Specifically, we demonstrate the importance of the prisoner's dilemma as jointly the firms would prefer *not* to have the innovation that inherently limits the profitability of spatial price discrimination. It is only the fear that the rival will purchase the license that allows the innovator to establish a dominant strategy in which each firm pays for the license. This differs from the case of process innovation in the Cournot quantity model. We show that as for high levels of c, the outsider will prefer to sell to only one firm.

There are a number of possible extensions of this work. One of our basic assumptions has been that regardless of the licensing decision, the full market is served. This could be modified. First, when the reservation price is low enough, purchasing the license could lower transport cost so that the firms could acquire new customers. Second, when the innovator is an insider, the location advantage associated with lower transport cost becomes muted. This may imply that fixed fee licensing and the royalty licensing could be profitable and even change the relative ordering. A second extension might imagine more than one competitor to an inside innovator. This may alter the profitability of alternative licensing. Finally, one might consider downward sloping demand curves at each point in the market suggesting another potential gain to the firms from purchasing the license.

While these extensions remain as future work, this paper contributes by highlighting the importance of innovations that reduce transport costs. Such innovations have unique value under spatial price discrimination and give rise to incentives in pricing and location not previously examined.

Appendix:

$$\pi_1^D = -\frac{1}{2(8c^2-7cd-16tc+2d^2+8t^2+7td)^2}(24c^5 - 120tc^4 - 88c^4d + 352c^3dt + 114c^3d^2 + 240t^2c^3 - 528t^2c^2d - 342tc^2d^2 - 240t^3c^2 - 75c^2d^3 + 26cd^4 + 150ctd^3 + 352cdt^3 + 342cd^2t^2 + 120t^4c - 4d^5 - 75t^2d^3 - 26td^4 - 114t^3d^2 - 88t^4d - 24t^5)$$

$$\pi_2^D = -\frac{1}{(8c^2-7cd-16tc+2d^2+8t^2+7td)^2}(12c^5 - 60tc^4 - 16c^4d + 64c^3dt + 7c^3d^2 + 120t^2c^3 - 96t^2c^2d - 21tc^2d^2 - 120t^3c^2 - c^2d^3 + 2ctd^3 + 64cdt^3 + 21cd^2t^2 + 60t^4c - 12t^5 - t^2d^3 - 7t^3d^2 - 16t^4d)$$

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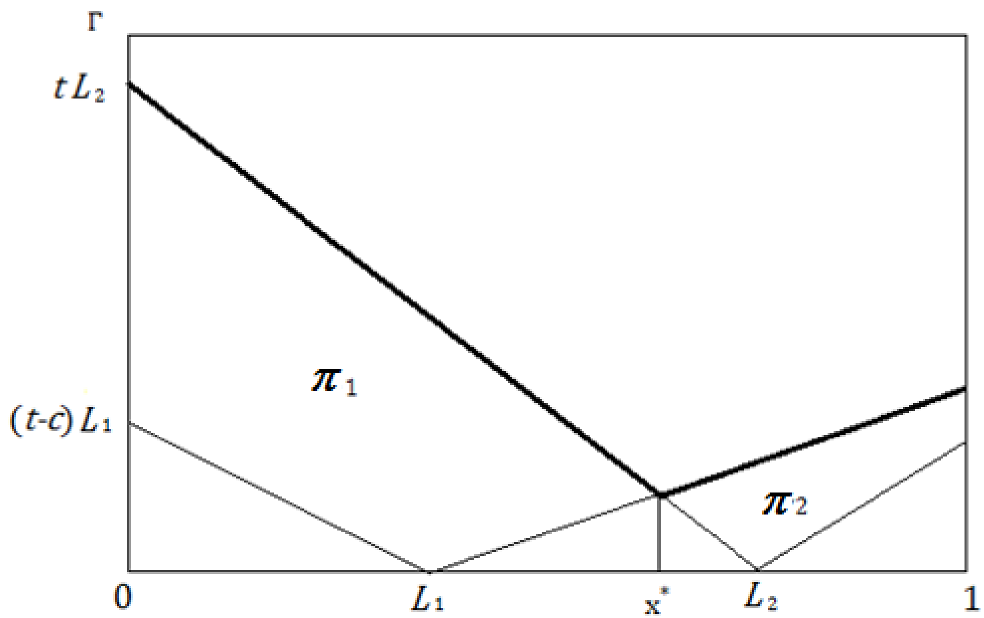
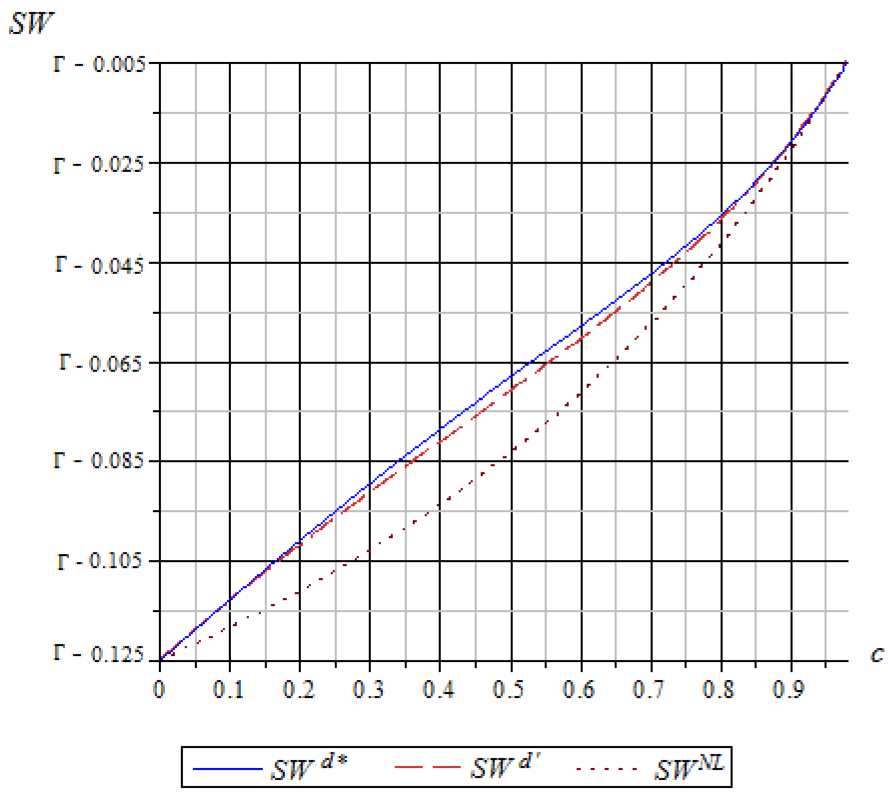
Figure 1: Spatial Price Discrimination in Duopoly Competition



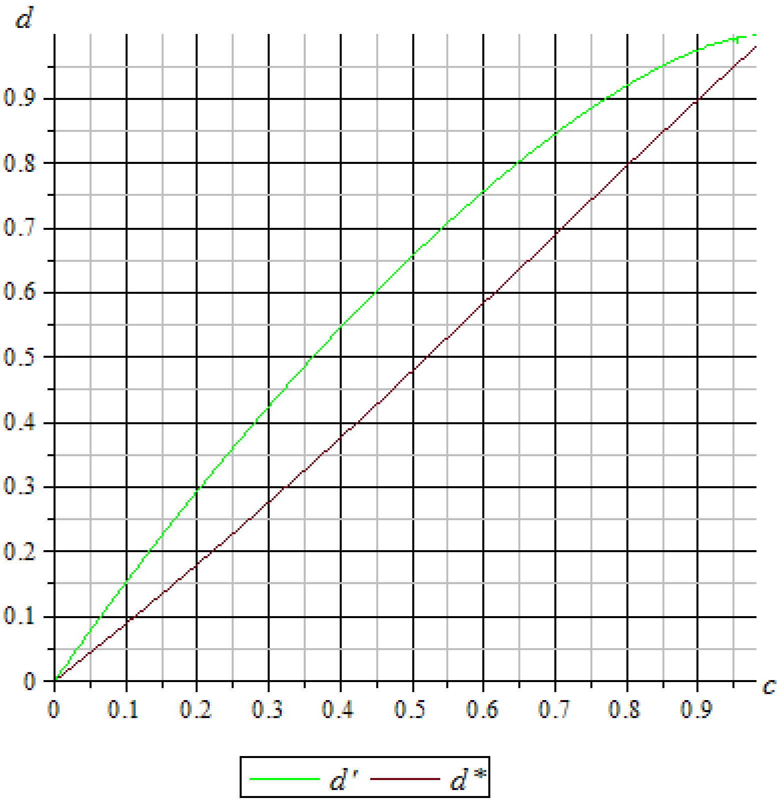
Note: The delivered price schedule is depicted by the thick lines and π_i is Firm i's profit earned on the difference between the price schedule and the delivered cost.

Figure 2: Social Welfare and the Distance Fee Licensing



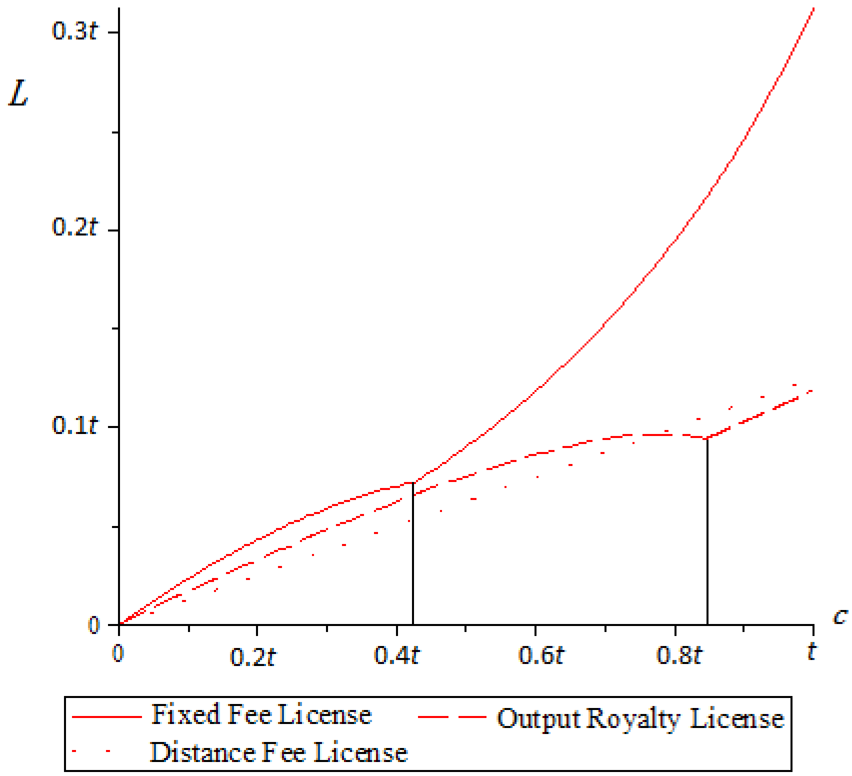
Notes: i) SW^{d^*} represents social welfare with the socially optimal distance fee, $SW^{d'}$ represents social welfare with the equilibrium distance fee, SW^{NL} represents social welfare without licensing. ii) Inelastic demand implies that social welfare is the willingness to pay Γ minus the real resources spent on transportation.

Figure 3: Equilibrium Distance Fee and Socially Optimal Distance Fee



Note: d' represents the equilibrium distance fee and d^{*} represents the socially optimal distance fee.

Figure 4: Representation of Proposition 5



Note: L is the licensing revenue of outside innovator.

Table 1: Locations and Distance Fee Licensing

c	Locations		
	(L_1^{NL}, L_2^{NL})	$(L_1^{d'}, L_2^{d'})$	$(L_1^{d^*}, L_2^{d^*})$
0.1t	(0.263, 0.763)	(0.256, 0.765)	(0.253,0.759)
0.2t	(0.278, 0.778)	(0.265, 0.782)	(0.258,0.770)
0.3t	(0.294, 0.794)	(0.276, 0.799)	(0.266,0.784)
0.4t	(0.313, 0.813)	(0.290, 0.818)	(0.277,0.801)
0.5t	(0.333, 0.833)	(0.308, 0.840)	(0.292,0.821)
0.6t	(0.357, 0.857)	(0.330, 0.863)	(0.314,0.846)
0.7t	(0.385, 0.885)	(0.357, 0.890)	(0.343,0.876)
0.8t	(0.417, 0.917)	(0.392, 0.920)	(0.382,0.911)
0.9t	(0.455, 0.955)	(0.438, 0.956)	(0.433,0.953)

Note: i) L_i^{NL} is Firm *i*'s location associated without licensing, $L_i^{d'}$ is Firm *i*'s location with the equilibrium distance fee, and $L_i^{d^*}$ is Firm *i*'s location given the socially optimal distance fee. ii) The illustration makes clear that $L_1^{NL} > L_1^{d'} > L_1^{d^*}$ and $L_2^{d'} > L_2^{NL} > L_2^{d^*}$.

Table 2: Transport Costs with and without Distance Fee Licensing

c	TC^{NL}	$TC^{d'}$	TC^{d^*}
0.1*t*	0.118*t*	0.113*t*	0.112*t*
0.2*t*	0.111*t*	0.102*t*	0.101*t*
0.3*t*	0.103*t*	0.091*t*	0.089*t*
0.4*t*	0.094*t*	0.081*t*	0.078*t*
0.5*t*	0.083*t*	0.071*t*	0.068*t*
0.6*t*	0.071*t*	0.061*t*	0.058*t*
0.7*t*	0.058*t*	0.049*t*	0.047*t*
0.8*t*	0.042*t*	0.037*t*	0.036*t*
0.9*t*	0.023*t*	0.021*t*	0.020*t*

Note: i) TC^{NL} is the transport cost without licensing, $TC^{d'}$ is the transport cost with the equilibrium distance fee, and TC^{d^*} is the transport cost given the socially optimal distance fee. ii) Inelastic demand implies that social welfare is the willingness to pay Γ minus the real resources spent on transportation.

Endnotes:

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[1] Equating the delivered prices from the two firms: $t(L_2 - x^*) = (t-c)(x^* - L_1) \Rightarrow x^* = \frac{-L_1 t + L_1 c - tL_2}{-2t+c}$.

[2] While solving the constraint for r yields two roots, only one returns locations within the unit market.

[3] While the expressions are complicated, this demonstration is straightforward and available upon request.

[4] Firm 2's profit declines monotonically with d: $\frac{\partial \pi_2^D}{\partial d} = -\frac{2(t-c)^2 d^4 + 21(t-c)^3 d^3 + 72(t-c)^4 d^2 + 96d(t-c)^5 + 40(t-c)^6}{(2d^2 + 7d(t-c) + 8(t-c)^2)^3} < 0$.

[5] Returning $L_1^D = \frac{2c^2 - 2cd - 4tc + 2t^2 + 2td + d^2}{8c^2 - 7cd - 16tc + 2d^2 + 8t^2 + 7td}$ and $L_2^D = \frac{2(3c^2 - 3cd - 6tc + 3t^2 + 3td + d^2)}{8c^2 - 7cd - 16tc + 2d^2 + 8t^2 + 7td}$ to TC^D and minimizing with respect to d yields d=0.

[6] $TC^{NL} - TC^{d1} = \frac{1}{8}t - \frac{t(t-c)}{4(2t-c)} = \frac{tc}{8(2t-c)} > 0$ where TC^{NL} represents the total transport cost without licensing and TC^{d1} represents the total transport cost with one license sold.