

TRIP CHAINING: WHO WINS WHO LOSES?

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Abstract

There has been a very large amount of research devoted to the study of chains of activities. The initial studies were developed in geography (space and time description of human activity, as described by Torsten Hägerstrand and Peter Hagget) and in economics (starting with the seminal work of Gary Becker). More recently, transportation scholars (see for example the studies of Chandra Bhat or of Kay Axhausen) have started to develop sophisticated econometric models to describe the chain of activities during the whole day, or the whole week. One rationale for this research is the fact that users are increasingly sophisticated and spend more and more time on trips other than from home to work. Thus, lengthy trips with many stops can now be envisaged (with sometimes one of these stops being at the office) which change the structure of travel demand.

We propose here a complementary avenue of research covering the following questions: what are the impacts of the chain of activities on the decisions of the firm? The fact that users change their activity patterns does influence the locations of the firms (see for example the emergence of large shopping areas near railway stations or even inside railway stations and airports), as well as their pricing strategies. The questions are: Is the market more or less competitive when trip chaining is taken into account? Are human activities more or less concentrated as users are more involved in trip chaining?

Keywords: trip chaining, discrete choice model, general equilibrium model, imperfect competition, wage competition.

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Trip chaining: who wins, who loses?

1. INTRODUCTION

There has been a considerable amount of research devoted to the study of activity patterns. The initial studies were developed in geography with the space-time description of human activity advanced by Hägerstrand (1970, 1975) and Haggett (1977) and in economics (starting with the seminal work of Gary Becker (1987)). More recently, transportation scholars have started to develop sophisticated econometric models to describe the chain of activities during the whole day of individuals using diary survey data (e.g. Axhausen (2002)). Adler and Ben-Akiva (1979) present a model for a day non-work travel pattern. Bowman and Ben-Akiva (2001) include work as an activity in their discrete choice model system, which can be used for travel forecasting. Bhat and Singh (2000) develop a representation of the workday activity-travel pattern, in which several activity stops can be made during different periods of the day (sub-patterns). Golob (2000) develops and tests a household trip generation model, which forecasts activity participation, trip chaining and travel time as a function of household characteristics and accessibility indices. Kuppam and Pendyala (2001) also use a structural equations modelling approach applied to activity based travel survey data collected in Washington DC. Bhat et al (2004) focus on multiday activity generation.

Trip chaining is considered to be a growing phenomenon in travel and activity behaviour, as individuals try to reduce the amount of travel time needed to complete daily activities, given the limitations of their time budget. In their empirical analysis using data from US metropolitan areas, Bhat and Singh (2000) show that stops for shopping or socio-recreational activities are most likely to be made during the evening commute or later in the evening. Recker et al (2001) examine the effect that efficient travel decisions, like trip chaining, can have on the potential to engage in additional activities. Applying their numerical model, in which a generalised household cost function is minimised subject to time-related and routing constraints, to data from Portland, Oregon, they show potential household accessibility improvements with trip chaining. Hensher and Reyes (2000) use econometric analysis to look at the potential barrier trip-chaining creates to attracting car users to switch to public transport. In the field of consumer research, Brooks et al (2004) apply diminishing sensitivity and reference point dependence theory to trip chaining and investigate experimentally preferences for distance and clustering of stops in the activity chain.

In this paper we pursue a different avenue of research and examine the effect that trip chaining by households has on the pricing and wage decisions of firms. Are firms more or less competitive? Our starting point is a theoretical, symmetric model of a city, in which households live in the city centre and there is imperfect competition between firms located in subcentres (de Palma and Proost 2005). In the original model individuals made separate working and shopping trips. Here we relax this assumption and allow consumers to shop at the subcentre where they work. The model is first briefly described in Section 2 and the short-run equilibrium with trip chaining is then

derived and compared to the results of the original model. A small numerical illustration is included. In Section 3 we look at the welfare implications of trip chaining and in Section 4 conclude.

2. THEORETICAL FRAMEWORK

2.1. *Model Setting*

The study imperfect competition in a city both with and without congestion has been analysed recently for a closed economy by de Palma and Proost (2005). In their model, households are constrained to make separate trips for shopping and working, so trip-chaining is de facto not permitted. In this paper we relax this assumption and allow residents to shop at their work location without making a separate journey. In the current paper, the model set-up is symmetric and we do not include congestion in order to focus solely on the effect trip-chaining has on the price equilibrium. In this section we provide a brief description of the model set-up and derive the relevant expressions for the symmetric price equilibrium without congestion but with trip chaining.

Residents live in a city centre and travel to one of n subcentres to work and shop. In the symmetric city, the subcentres are equidistant from the centre and there are at least two subcentres. Residents first choose where to work and then decide whether to shop at their work location or at another subcentre; however residents can only travel between the centre and each subcentre and not between subcentres (see Figure 2-1). A homogeneous good is produced in the city centre and used as an intermediate input for the differentiated good, which is produced in the subcentres. Thus, both firms and consumers incur travel costs. In this general equilibrium setting, the numéraire homogeneous good represents all production in the economy other than the differentiated good and all profits are returned to the households. The labour market is also considered separately and jobs in the differentiated industry are heterogeneous. Only one differentiated product variant is produced at each subcentre by a single firm and each household will consume one unit of differentiated good and supply one unit of labour for its production. Hence, in the current formulation, demand for the differentiated good is inelastic and, if the labour market is assumed to be fully flexible, the product and labour markets will clear. All remaining labour (θ) and income is devoted to the homogeneous good and there is therefore no possibility of non-consumption or unemployment.

The total production possibilities of an economy with N households and n firms can then be expressed in terms of the following identity for labour supply and demand:

$$(1 + \theta)N = D + c^1 D + nF + (\alpha^w + \alpha^d + \alpha^h) \sum_{i=1}^N t_i D_i + nK + G, \quad (1)$$

where $D (= \sum D_i)$ is the total demand for the differentiated good, c^1 is the marginal production cost of the intermediate input, F is the fixed production cost for each firm and transportation costs for commuting, shopping and supply of goods are given by $(\alpha^w + \alpha^d + \alpha^h) \sum_{i=1}^N t_i D_i$. These last are exogenous since there is no congestion. Each

subcentre requires some road infrastructure (K), which is paid for by a levy (S) on firms and head-tax (T) on consumers. Finally, G denotes residual consumption of the homogeneous good.

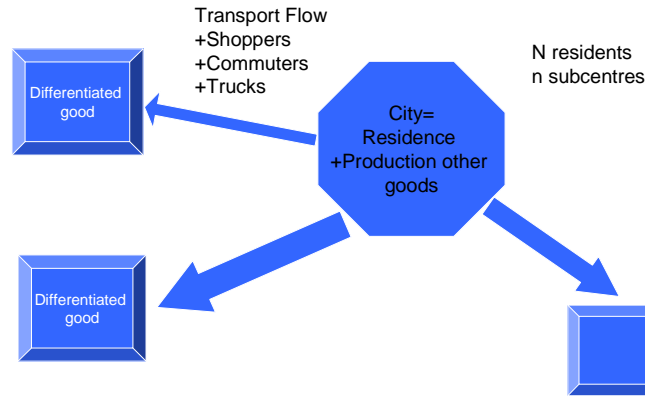


Figure 2-1 Schematic of city layout

2.2. Household Preferences

Household utility is represented by a linear function of the utility obtained from consumption of the differentiated and homogeneous goods and the disutility of supplying labour to the production of these goods. Using the household budget equation to substitute for consumption of the homogeneous good, an indirect conditional utility function can be derived to express household preferences. In this case the utility function represents the preferences of a household that buys differentiated good k and supplies labour to subcentre i :

$$U_{ik} = \tilde{h}_k - p_k - \alpha^d t_k + w_i - \tilde{\beta}_i - \alpha^w t_i + \theta(1 - \beta) + \frac{1}{N} \sum_l \pi_l - T. \quad (2)$$

Each of the N households is paid a wage, w_i , for working at subcentre i and buys one unit of variant k at price, p_k . Both prices and wages will be determined by the model. The parameters α^w and α^d represent, respectively, the number of commuting and shopping trips the consumer¹ undertakes per unit of production (respectively consumption) of the differentiated good. They are positive constants. The travel time required for shopping activities, t_k , is zero if there is trip-chaining. Otherwise, in the symmetric case, commuting and shopping travel times are identical and positive ($t_k = t_i = t > 0$). Each household also receives a share of the firms' profits (π).

The utility of consumption of differentiated product variant k is given by an intrinsic quality component h_k and a stochastic component: $\mu^d \varepsilon_k$:

$$\tilde{h}_k = h + \mu^d \varepsilon_k, \quad (3)$$

¹ In the following we will use household and consumer interchangeably as it is easier to consider the household as a single worker or shopper.

and the disutility of labour at subcentre i is similarly given by the following two components:

$$\tilde{\beta}_i = \beta - \mu^w \varepsilon_i. \quad (4)$$

Hence, all households will value the quality of all product variants in the same way and will experience the same disinclination to work at all subcentres. However, the households will still vary in their tastes: the parameters ε_i and ε_k represent the intrinsic heterogeneity of consumer tastes and are assumed to be i.i.d. double exponentially distributed. The parameters μ^w and μ^d determine the degree of heterogeneity of preferences. In order to apply the nested logit approach, consistency implies that: $0 < \mu^d \leq \mu^w$, so that households' preferences for their choice of workplace are at least as strong as their preferences for shopping location.

Substitution of (3) and (4) in the utility formulation (2) results in a random utility function for which the choice probabilities can be determined using the nested logit model. We use a heuristic approach to derive the probabilities of working and shopping at a given subcentre: the resident first selects his workplace and then chooses where to shop. The consumer surplus associated with the resident's shopping alternatives, given his work location, affects his initial workplace choice. A full derivation of the choice probabilities can be obtained using the Generalised Extreme Value (GEV) approach of McFadden (Mc Fadden 1978). The decision tree for the nested logit is shown in Figure 2-2 below.

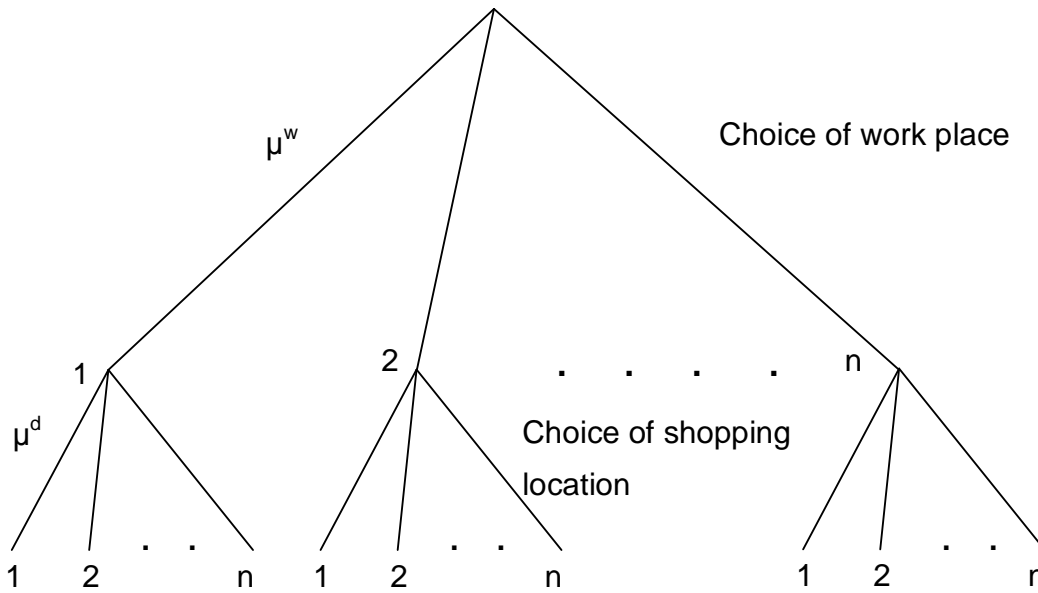


Figure 2-2 Nested logit

In order to derive the symmetric price equilibrium, we first suppose that firm I deviates and sets price p_1 for its product and pays its workers a wage w_1 . All other firms charge p^* and pay w^* .

The probability of working at subcentre I is given by a binary nested logit model, as follows:

$$P_1^w(w_1, w^*) = \frac{e^{\frac{w_1 - \alpha^w t + CS_1 - \beta}{\mu^w}}}{e^{\frac{w_1 - \alpha^w t + CS_1 - \beta}{\mu^w}} + (n-1)e^{\frac{w^* - \alpha^w t + CS_{-1} - \beta}{\mu^w}}}, \quad (5)$$

where CS_1 is the consumer surplus for a resident who works at subcentre 1

$$CS_1 = h + \mu^d \log \left[e^{\frac{-p_1}{\mu^d}} + (n-1)e^{\frac{-p^* - \alpha^d t}{\mu^d}} \right]. \quad (6)$$

The first term in the bracket refers to the resident who shops and works at subcentre 1 (trip chains), while the second term refers to the resident who works at subcentre 1 but shops elsewhere with travel time t .

CS_{-1} is the consumer surplus for a resident who works at any other subcentre k , say

$$CS_{-1} = h + \mu^d \log \left[e^{\frac{-p_1 - \alpha^d t}{\mu^d}} + e^{\frac{-p^*}{\mu^d}} + (n-2)e^{\frac{-p^* - \alpha^d t}{\mu^d}} \right]. \quad (7)$$

The first term in the bracket refers to the resident who works at k and shops at subcentre 1 , the second term to the resident who trip chains (works and shops at k) and the third term to the resident who works at k and shops at subcentre $j \neq k$ or 1 , with travel time t .

The probability of working at a subcentre (other than subcentre 1) is given by

$$P_{-1}^w = \frac{e^{\frac{w^* - \alpha^w t + CS_{-1} - \beta}{\mu^w}}}{e^{\frac{w_1 - \alpha^w t + CS_1 - \beta}{\mu^w}} + (n-1)e^{\frac{w^* - \alpha^w t + CS_{-1} - \beta}{\mu^w}}}. \quad (8)$$

The denominator is the same as in (5) since the consumer still has the same chance of working at subcentre 1 and being paid w_1 or another subcentre and being paid w^* .

The probability of a resident shopping at subcentre 1 given he works there is given by

$$P_{1|1}^s(p_1, p^*) = \frac{e^{\frac{h - p_1}{\mu^d}}}{e^{\frac{h - p_1}{\mu^d}} + (n-1)e^{\frac{h - p^* - \alpha^d t}{\mu^d}}}. \quad (9)$$

The first term of the denominator refers to a resident who trip chains and the second to the resident who works at subcentre 1 but shops elsewhere.

The probability of a resident shopping at subcentre 1 , given he does not work there is given by

$$P_{l-1}^s = \frac{e^{\frac{h-p_1-\alpha^d t}{\mu^d}}}{e^{\frac{h-p_1-\alpha^d t}{\mu^d}} + e^{\frac{h-p^*}{\mu^d}} + (n-2)e^{\frac{h-p^*-\alpha^d t}{\mu^d}}}. \quad (10)$$

In this case the terms in the denominator cover the options of: a) shopping at subcentre 1 but working elsewhere so there is a travel time; b) shopping and working at some subcentre ($k \neq 1$ say); and c) shopping at k but working at subcentre 1 ($j \neq k$ or 1), so again there is a travel component. The resident has to travel to subcentre 1, so t appears in the numerator. Note that in the above equations the h and β terms cancel.

Let $N_1^w = NP_1^w$, the proportion of households that work at subcentre 1. Then we can write the probability of shopping at subcentre 1 as

$$N_1^s = N_1^w P_{11}^s + N(1 - P_1^w) P_{l-1}^s. \quad (11)$$

We also know from market clearing that $N_1^w = N_1^s$ and by substitution in (11) we get

$$P_1^w [1 - P_{11}^s + P_{l-1}^s] - P_{l-1}^s = 0, \quad (12)$$

which provides a relation between the price p_1 and wage w_1 set by firm 1.

2.3. Firms

In general, the profit of firm i can be written:

$$\pi_i(w, p) = (p_i - w_i - c^1 - \alpha^h t) NP_i^w - (F + S) \quad \forall i = 1 \dots n, \quad (13)$$

where the demand $D_i = NP_i^d = NP_i^w$ under market clearing conditions. Since firm 1 deviates, his profit becomes

$$\pi_1(w_1, w^*, p_1, p^*) = (p_1 - w_1 - c^1 - \alpha^h t) NP_1^w - (F + S). \quad (14)$$

Firms compete in a non-cooperative Nash game with their own prices and wages as the strategic variables. Since from (12) we know that p_1 determines w_1 and vice versa, we take the wage as the strategic variable for firm 1 and write $p_1 = g_1(w_1)$. Note that: $g_1(w_1) = g(w_1, w^*, p^*)$. Then, further assuming that firm 1 takes the prices and wages of the other firms as given, the first order condition for profit maximisation by this firm is given by

$$\frac{d\pi_1}{dw_1} = \left[\left(\frac{dg_1}{dw_1} - 1 \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(\frac{1 - P_1^w}{\mu^w} \right) \right] NP_1^w = 0. \quad (15)$$

In the next subsection, we derive an expression for the key strategic term dg_1/dw_1 .

2.4. Market equilibrium

In order to derive an expression for a candidate Nash equilibrium from the profit maximisation condition and prove its existence, we first need to determine the

derivative of the price at firm I with respect to its wage (dg_1/dw_1 in equation (15)). I added in a few place inequalities inside the equations.

Lemma 1 $\frac{dg_1}{dw_1} = \frac{-\mu}{1+(1-\mu)\Phi} < 0$ where $\mu \equiv \frac{\mu^d}{\mu^w} \leq 1$ and $\Phi \equiv P_{11}^s - P_{11-1}^s > 0$.

Lemma 1 is proved in the Appendix.

Substitution of dg_1/dw_1 from Lemma 1 in (15) leads to

$$\left[\left(\frac{-\mu}{1+(1-\mu)\Phi(p_1, p^*)} - 1 \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(\frac{1 - P_1^w}{\mu^w} \right) \right] N P_1^w = 0 \quad (16)$$

Replacing P_1^w in (16) in terms of the conditional shopping probabilities (P_{11}^s and P_{11-1}^s) from equation (12), we obtain

$$\left[\left(\frac{-(1+\mu) - (1-\mu)\Phi}{1+(1-\mu)\Phi} \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(\frac{1 - P_{11}^s}{\mu^w [1 - \Phi]} \right) \right] N \frac{P_{11-1}^s}{[1 - \Phi]} = 0. \quad (17)$$

Now, at equilibrium in the symmetric case, $p_1 = p^*$ and we can therefore rewrite the conditional shopping probabilities (9) and (10) as

$$P_{11}^s = \frac{1}{1+(n-1)\lambda} > \frac{1}{n}, \quad (18)$$

$$P_{11-1}^s = \frac{\lambda}{1+(n-1)\lambda} < 1, \quad (19)$$

where $\lambda \equiv e^{-\alpha^d t / \mu^d} > 0 \in (0, 1)$ from our model assumptions. Moreover, we can write

$$\Phi = P_{11}^s - P_{11-1}^s = \frac{1 - \lambda}{1+(n-1)\lambda}. \quad (20)$$

Note, $\Phi > 0$ so there is a greater probability of trip chaining than of working and shopping in separate locations. P_{11}^s is also increasing with λ : large travel costs or weak preference for shopping location increase the probability of trip chaining. There is, however, an equal probability of working at any of the firms ($P_1^w = 1/n$). Substitution of expressions (18), (19) and (20) in (17) allow us to specify the candidate Nash equilibrium.

Proposition 1 When trip chaining is permitted, there exists a unique symmetric Nash equilibrium in prices and wages, for two firms or more in the market. The price-wage equilibrium is given by

$$p^* - w^* = c^1 + \alpha^h t + (\mu^w + \mu^d) \frac{n}{n-1} - \frac{n\mu^d}{n-1} \left\{ \frac{(1-\mu)(1-\lambda)}{[2-\mu+(n-2)\lambda+\mu\lambda]} \right\}. \quad (21)$$

Proposition 1 is proved in the Appendix.

From (13), in equilibrium, a firm's gross profit per household (neglecting fixed costs) is

$$\pi^* = \frac{(\mu^w + \mu^d)}{n-1} - \frac{\mu^d}{n-1} \left[\frac{(1-\mu)(1-\lambda)}{(2-\mu + (n-2)\lambda + \mu\lambda)} \right]. \quad (22)$$

Using the fact that $\mu < 1$ and $\lambda < 1$, it can be verified that $\pi^* > 0$. The comparative statics result is straightforward and left to the reader. The relationship between the mark-up in price over wage and profit and the parameters $n, \alpha^d, \mu^w, \mu^d, t$ and λ is discussed in Section 4 using a numerical example.

It is possible to perform the same analysis, within the nested logit framework, for the case where consumers have to work and shop at different subcentres (i.e. perform single purpose trips). In this case $P_{\parallel}^s = P_{\parallel-1}^s = P_1^s = P_1^w = 1/n$ and the symmetric Nash equilibrium in prices and wages is given by

$$(p^* - w^*)_{ntc} = c^1 + \alpha^h t + (\mu^w + \mu^d) \frac{n}{n-1} \quad (23)$$

This is in fact the same as the equilibrium which can be derived when working and shopping decisions are taken independently (see de Palma and Proost 2005), with the restriction $\mu^d \leq \mu^w$ for the nested logit approach (Anderson et al 1992). In this case profits only depend on the consumer heterogeneity parameters and number of firms.

We can now compare the symmetric trip chaining equilibrium with the above symmetric, reference equilibrium.

Proposition 2 The symmetric firm mark-up when households can trip chain cannot exceed the mark-up when households can only perform single purpose trips. The mark-ups are in fact equal when $\mu^d = \mu^w$

Proof

Using (23), (21) can be rewritten as

$$p^* - w^* = (p^* - w^*)_{ntc} - \frac{n\mu^d(1-\mu)}{n-1} \left[\frac{(1-\lambda)}{(2-\mu + (n-2)\lambda + \mu\lambda)} \right]. \quad (24)$$

The difference in the mark-up between the two equilibria depends on the sign of the second term on the right hand side of (24). The terms outside the parentheses are non-negative for $n \geq 2$ (at least two firms are considered in the model) since $\mu \equiv \mu^d / \mu^w$ is less than or equal to one: $0 < \mu^d \leq \mu^w$ is a requirement of nested logit model. For the terms inside the parentheses, the numerator is positive as t, α^d and μ^d are all positive by definition and the denominator is also positive for $n \geq 2$. Hence the last term in (24) is always non-positive and the mark-up with trip chaining is at most equal to the mark-up without trip chaining. Q.E.D.

The intuition is that the demand curve for shoppers with trip chaining is flatter than the corresponding demand curve when households cannot shop and work at the same subcentre. In equilibrium, a firm sells its product to a larger number of its own workforce than to consumers who work at other subcentres. Thus, a decrease in the

price by one firm would attract additional non-trip chaining customers from other subcentres, while retaining the customers who already work for the firm. Hence, when trip-chaining is possible, a change in price would lead to a greater change in demand compared with the case without trip chaining and as a consequence, the equilibrium price with trip chaining is higher than without trip chaining. In a sense, trip chaining decreases the spatial market power of each firm, and therefore increases competitiveness and therefore decreases equilibrium prices and equilibrium profit (since market demand is inelastic).

3. WELFARE ANALYSIS

Proposition 3 In the symmetric equilibrium, the consumer surplus² when households can trip chain is larger than the consumer surplus when households must perform only single purpose trips. The difference in consumer surplus is given by

$$CS - CS_{ntc} = (p^* - p_{ntc}^*) + \mu^d \log \left[1 + \frac{\lambda^{-1} - 1}{n} \right]. \quad (25)$$

Proposition 3 is proved in the Appendix. Consumer surplus depends on price, rather than price minus wage. The price difference in (25) can be obtained from Proposition 2 by setting the wage equal to one (without loss of generality).

Although consumer surplus increases, firms' profits are smaller when households trip chain, compared with the reference equilibrium, as the price mark-up they can charge above the wages they pay is reduced. However, this negative effect is more than compensated for by the increase in consumer surplus, since the difference in prices are just transfers between households and firms.

Proposition 4 In the symmetric equilibrium, welfare² is greater when households can trip chain, than when they have to perform only single purpose trips. The difference in welfare is given by

$$W - W_{ntc} = \mu^d \log \left[\frac{\lambda^{-1} - 1}{n} + 1 \right]. \quad (26)$$

Proposition 4 is proved in the Appendix.

When consumers are able to trip chain there is both a direct benefit to society from the reduced travel cost and an additional cost due to the reduction in consumer variety. Since each consumer trip chains with probability $P_{||}^s > 1/n$, the term $\alpha^d t/n$ represents the lower bound for the reduction in travel cost. This can be obtained from (26) by setting $\lambda^{-1} = 1 + \varepsilon$ where $\varepsilon = \alpha^d t / \mu^d \ll 1$, for small travel times t . Then, the welfare saving

$$W - W_{ntc} = \mu^d \log \left[1 + \frac{\varepsilon}{n} \right] = \mu^d \frac{\varepsilon}{n} + O(\varepsilon^2) = \frac{\alpha_d t}{n} + O(\varepsilon^2),$$

² Consumer surplus and Welfare are calculated per household

is approximately equal to the average travel time saving since $P_{||}^s \approx 1/n$ if $\lambda \approx 0$. More generally, we have the following inequality:

$$W - W_{ntc} < \frac{\alpha_d t}{n},$$

which shows that the welfare savings are generally smaller than the travel time saving. The reason is that, when an individual decides to stay at his work place and to trip chain in order to economize travel time, there is one $1/n$ th of chances that the product purchased at the work place does not fit exactly her choice (i.e. without trip chaining, the individual would not shop at his workplace but elsewhere). Thus trip chaining not only decreases travel time but also decreases the variety of goods offered. For the extreme case, where transportation costs are very high, almost all consumers will trip chain and the variety offered will decrease from n to 1 (and the benefit from variety will decrease from $\log(n)$ to 0).

4. NUMERICAL EXAMPLE

The trip chaining equilibrium in price and wages, (24), depends in a complex way on a number of parameters: in particular $\mu^w, \mu^d, \alpha^d, n, \lambda \equiv e^{-\alpha^d t / \mu^d}$ and travel time, t . The following numerical exercise illustrates the effect of each of these parameters on the price-wage equilibrium and also on profit, consumer surplus and welfare.

We use the simple, stylised example of an economy of one day³. As a reference, we assume there are three firms offering the differentiated good. Each resident makes one commuting trip and one shopping trip per day, giving a total transport time of one hour. He also supplies 7.5 hours of labour, of which one hour is spent on the production of the differentiated good. Truck deliveries are such that each truck contains sufficient intermediate good to produce 50 units of the differentiated good. One unit of the differentiated good requires an intermediate input that can be produced using 0.1 units of homogeneous labour. Finally, we neglect fixed costs and levies, as these do not affect the short-run equilibria or welfare analysis, and present gross profits per household.

In Table 4-1 above we examine the effect on price minus wage and gross profit (π) of varying the consumers' preference for work and shopping locations (μ^w and μ^d , respectively), number of shopping trips (α^d) and travel time, for the equilibria with and without trip chaining. We also look at the effect of increasing the number of firms.

When consumers can trip chain, profits increase as μ^w increases since the strong preference for working location means that a firm can pay lower wages (or charge higher prices) without losing workers. Similarly, a weak preference for shopping location (small μ^d) necessitates firms charging lower prices to retain shoppers. Profits also decrease when there are more firms due to increased competition. Similar effects are also seen for changes in these parameters in the no trip-chaining reference case.

³ This example is based on the numerical work presented in de Palma et al (2004)

μ^d	μ^w	α^d	n	t (hours)	λ	p^*-w^*	$p_{ntc}-w_{ntc}$	π^*	π_{ntc}	$\Delta\pi^*$ (%) [†]	$\Delta\pi$ (%) ^{††}
1	2	1	3	0,5	0,61	4,488	4,610	1,459	1,500	2,7	0,0
1	5	1	3	0,5	0,61	8,923	9,110	2,938	3,000	2,1	101,3
0,1	2	1	3	0,5	0,01	3,188	3,260	1,026	1,050	2,3	-29,7
1	2	1	10	0,5	0,61	3,410	3,443	0,330	0,333	1,0	-77,4
1	2	0,2	3	0,5	0,90	4,585	4,610	1,492	1,500	0,6	2,2
1	2	2	3	0,5	0,37	4,379	4,610	1,423	1,500	5,1	-2,5
1	2	1	3	2	0,14	4,259	4,640	1,373	1,500	8,5	-5,9
1	2	1	3	0,25	0,78	4,543	4,605	1,479	1,500	1,4	1,4

Table 4-1 Comparative statics with and without trip chaining

† The difference in profit is calculated as a percentage of the symmetric case without trip chaining

†† The difference in profit is calculated as a percentage of the reference case highlighted in the first row (trip chaining only)

Interestingly, however, we see that, when consumers can work and shop at the same subcentre, the number of shopping trips they make (α^d) plays a role. If consumers do not make frequent shopping trips then firms can make higher profits. A small value of α^d means that the travel cost for shopping trips is low, which is equivalent to the demand curve becoming steeper. A smaller proportion of workers trip chain, so any decrease in price would still attract shoppers from other subcentres but these are added to a smaller number of trip-chaining workers. Decreasing or increasing the travel time from the city centre to the subcentres has the same effect on profits as does α^d . A longer travel time means higher travel costs and, in this case, a higher proportion of the workforce prefers to trip-chain to minimise these costs. The demand curve is consequently flatter, since decreasing the price at one subcentre would attract customers from other subcentres in addition to the households that trip chain, and prices and profits are lower. For the no trip-chaining case, the price mark-up over wage does depend on travel time because of travel costs for the intermediate good but profits are independent of t . Note also that, for the trip chaining case, profit increases with λ .

It is clear from Table 4-1 that when consumers can trip chain, firms cannot make greater profits than when consumers can only make single purpose trips. The magnitude of the difference in profits obviously depends on the values of the input parameters but the difference is large for long travel time or high frequency of shopping trips. In Table 4-2 we present the difference in consumer surplus and welfare (per household) between the two equilibria.

As expected, the largest gains in consumer surplus and welfare with trip chaining are seen when consumers have a low preference for shopping location, so they are more likely to trip chain and firms also charge lower prices. Note that a stronger consumer preference for working location has no effect on welfare but decreases consumer surplus as firms are able to increase prices.

μ^d	μ^w	α^d	n	t (hours)	λ	CS^*-CS_{ntc}	W^*-W_{ntc}	W^*-W_{ntc} (%GDP)
1	2	1	3	0,5	0,61	0,07	0,20	2,3
1	5	1	3	0,5	0,61	0,01	0,20	2,3
0,1	2	1	3	0,5	0,01	0,32	0,39	4,6
1	2	1	10	0,5	0,61	0,03	0,06	0,7
1	2	0,2	3	0,5	0,90	0,01	0,03	0,4
1	2	2	3	0,5	0,37	0,22	0,45	5,3
1	2	1	3	2	0,14	0,76	1,14	13,4
1	2	1	3	0,25	0,78	0,03	0,09	1,1

Table 4-2 Welfare effects with and without trip chaining

5. CONCLUSIONS

There has been a considerable amount of work undertaken to study the empirical aspects of trip chaining, and more generally of activity patterns. Yet, these works tend to focus on the consumer side, only, and therefore neglect the impacts of trip chaining on the quality of activity, and on the profitability of market places. We have shown that trip chaining has a positive impact on consumers, since on one hand the equilibrium price decreases and on the other hand, the average travel cost decreases. Of course, the variety available to the consumer decreases also since a certain number of consumers are now willing to economize on variety (that is, these consumers are willing to purchase a good which is not the optimal one) in order to economize on travel time. Yes, consumers benefit from trip chaining. Of course, this shift from the optimal good to another good is possible only if the difference in the quality of the match between consumers and products is not too severe. Moreover, since market demand is constant and price decreases, firm profitability decreases. Since prices are only transfers, as expected the welfare increases with trip chaining. If we consider the long-run (free entry) equilibrium, trip chaining decreases profits and therefore induces exit. As a consequence, price increases, and product variety decreases, two bad signs on the consumer side.

Finally, we have considered a setup with constant demand. With elastic demand, trip chaining will induce more travellers to shop. We conjecture that trip chaining benefits will then be even stronger, from the social point of view.

APPENDICES

Appendix A1: Proof of Proposition 1.

Recall from Lemma 1 that at the candidate equilibrium

$$\frac{dp_1}{dw_1} = \frac{-\mu}{1 + (1 - \mu)\Phi} \quad (27)$$

where $\mu \equiv \frac{\mu^d}{\mu^w}$ and $\Phi \equiv P_{||}^s - P_{||-1}^s$. This expression is negative and single valued, so

that there exists a one-to-one relationship between p_1 and w_1 . Hence the set of prices is a convex, compact set and the equilibrium exists. Further (27) is constant, since μ , t and n are all exogenous.

Since a candidate equilibrium exists, we need only show that the profit function is quasi-concave to guarantee that the candidate equilibrium is the unique Nash solution.

At any extremum

$$\frac{d\pi_1}{dw_1} = \left[\left(\frac{dp_1}{dw_1} - 1 \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(\frac{1 - P_1^w}{\mu^w} \right) \right] NP_1^w = 0 \quad (28)$$

The corresponding second order condition is given by

$$\begin{aligned} \frac{d^2\pi_1}{dw_1^2} &= NP_1^w \frac{d^2 p_1}{dw_1^2} + NP_1^w \left[\left(\frac{dp_1}{dw_1} - 1 \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(-\frac{P_1^w}{\mu^w} \right) \left(\frac{1 - P_1^w}{\mu^w} \right) \right] + \\ &\quad \left[\left(\frac{dp_1}{dw_1} - 1 \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(\frac{1 - P_1^w}{\mu^w} \right) \right] NP_1^w \left(\frac{1 - P_1^w}{\mu^w} \right) \\ &= NP_1^w \frac{d^2 p_1}{dw_1^2} + NP_1^w \left(\frac{1 - P_1^w}{\mu^w} \right) \left[2 \left(\frac{dp_1}{dw_1} - 1 \right) + (p_1 - w_1 - c^1 - \alpha^h t) \left(\frac{1 - 2P_1^w}{\mu^w} \right) \right] \end{aligned} \quad (29)$$

From (28) we can replace $(p_1 - w_1 - c^1 - \alpha^h t)$ in (29) to get

$$\begin{aligned} \frac{d^2\pi_1}{dw_1^2} &= NP_1^w \frac{d^2 p_1}{dw_1^2} + NP_1^w \left(\frac{1 - P_1^w}{\mu^w} \right) \left(\frac{dp_1}{dw_1} - 1 \right) \left[2 - \left(\frac{1 - 2P_1^w}{1 - P_1^w} \right) \right] \\ &= NP_1^w \frac{d^2 p_1}{dw_1^2} + NP_1^w \left(\frac{1 - P_1^w}{\mu^w} \right) \left(\frac{dp_1}{dw_1} - 1 \right) \left(\frac{2 - 2P_1^w - 1 + 2P_1^w}{1 - P_1^w} \right) \\ &= NP_1^w \frac{d^2 p_1}{dw_1^2} + N \left(\frac{P_1^w}{\mu^w} \right) \left(\frac{dp_1}{dw_1} - 1 \right) \end{aligned} \quad (30)$$

Now

$$\begin{aligned}
\frac{d^2 p_1}{dw_1^2} &= \frac{d}{dw_1} \left[\frac{-\mu}{1 + (1 - \mu)\Phi} \right] \\
&= \frac{-\mu^2}{[1 + (1 - \mu)\Phi]^2} \frac{\partial \Phi}{\partial p_1} \frac{dp_1}{dw_1} \\
&= \frac{\mu^3}{[1 + (1 - \mu)\Phi]^3} \left[\frac{\partial P_{||}^s}{\partial p_1} - \frac{\partial P_{|-1}^s}{\partial p_1} \right] \\
&= \frac{\mu^3}{[1 + (1 - \mu)\Phi]^3} \left[-\frac{1}{\mu^d} [1 - P_{||}^s] P_{||}^s + \frac{1}{\mu^d} [1 - P_{|-1}^s] P_{|-1}^s \right] \\
&= \frac{-\mu^3}{\mu^d [1 + (1 - \mu)\Phi]^3} \Phi [1 - P_{||}^s - P_{|-1}^s]
\end{aligned} \tag{31}$$

From our model assumptions $0 < \mu \leq 1$ and $\mu^d > 0$. Further, we know that, at the candidate symmetric equilibrium, $\Phi > 0$, $P_{||}^s = \frac{1}{1 + (n-1)\lambda}$ and $P_{|-1}^s = \frac{\lambda}{1 + (n-1)\lambda}$ where $\lambda \equiv e^{-\alpha^d t / \mu^d} > 0$. Hence $[1 - P_{||}^s - P_{|-1}^s] = \frac{(n-2)\lambda}{1 + (n-1)\lambda}$ is non-negative for $n \geq 2$. Thus (31) is non-positive.

Substituting from (31) in (30) means that the first term on the right hand side of (30) is non-positive. We also know from (27) that $\frac{dp_1}{dw_1} < 0$, so the second term in (30) is negative. Hence $\frac{d^2 \pi_1}{dw_1^2}$ is strictly negative at any extremum (solution of the first-order equations) and thus the profit is quasi-concave. As a consequence, the candidate Nash equilibrium is a Nash equilibrium. QED.

Appendix A2: Proof of Proposition 3

In the symmetric equilibrium with trip chaining, consumer surplus per household is given by

$$CS = \mu^d \log \left[1 + (n-1)e^{\frac{-\alpha^d t}{\mu^d}} \right] + (h - p^*) \tag{32}$$

$$(\text{derived from } CS_1 = \mu^d \log \left[e^{\frac{h-p_1}{\mu^d}} + (n-1)e^{\frac{h-p^*-\alpha^d t}{\mu^d}} \right] \text{ with } p_1 = p^*)$$

When trip chaining is not an option, consumer surplus can be written as

$$CS_{ntc} = \mu^d \log[n] + h - p_{ntc}^* - \alpha^d t \tag{33}$$

$$(\text{derived from } CS_1 = \mu^d \log \left[e^{\frac{h-p_1-\alpha^d t}{\mu^d}} + (n-1)e^{\frac{h-p^*-\alpha^d t}{\mu^d}} \right] \text{ with } p_1 = p^*)$$

Subtracting (33) from (32) leads to

$$\begin{aligned} CS - CS_{ntc} &= (p^* - p_{ntc}^*) + \mu^d \log \left[\frac{1 + (n-1)\lambda}{n} \right] + \alpha^d t \\ &= (p^* - p_{ntc}^*) + \mu^d \log \left[1 + \frac{\lambda^{-1} - 1}{n} \right] \end{aligned} \quad (34)$$

where $\lambda \equiv e^{-\alpha^d t / \mu^d} > 0$. The second term in (34) is always positive for $n \geq 1$. From Propositions 1 and 2 we know that the mark-up is at most as large with trip chaining as without and, although this does not define the price levels unambiguously, we can set $w=1$ wlog in each case, leading to a non-negative price difference and hence larger consumer surplus.

Appendix A3: Proof of Proposition 4

The welfare function (per household) is derived from $W = \max E[U_{ik}]$ since profits are equally distributed among households (see for example Anderson and de Palma 1992). With trip chaining, the expected maximum utility obtained by the household at the second stage (when making shopping choices) is in fact the consumer surplus associated all possible shopping options given the choice of work location at the first stage in the nested logit tree. Welfare can then be calculated by maximising expected utility at the first stage, given by

$$W(n) = \max_k E[V'_k + \mu^w \varepsilon_k] \quad (35)$$

where

$$V'_i = \Xi + w^* - \beta - \alpha^w t + \mu^d \log \left[e^{\frac{h-p^*}{\mu^d}} + (n-1)e^{\frac{h-p^*-\alpha^d t}{\mu^d}} \right] \quad (36)$$

is commonly known as the composite utility or expected maximum utility and contains terms common to all residents who work at subcentre i plus the consumer surplus associated with all alternatives in the nest (in this case shopping locations given the choice of i th subcentre for work).

$$\Xi = \theta(1 - \beta) + \frac{n}{N} \pi - T = \theta(1 - \beta) + p^* - w^* - c^1 - \alpha^h t - \frac{n}{N} (F + K).$$

Now, (35) can be rewritten as

$$\begin{aligned}
W(n) &= \mu^w \log \left[\sum_i \exp\left(\frac{V_i'}{\mu^w}\right) \right] \\
&= \mu^w \log \left[n \exp \left(\frac{\Xi + w^* - \beta - \alpha^w t + \mu^d \log \left[e^{\frac{h-p^*}{\mu^d}} + (n-1)e^{\frac{h-p^*-\alpha^d t}{\mu^d}} \right]}{\mu^w} \right) \right] \\
&= \mu^w \log[n] + \hat{\Psi} - \alpha^w t + \mu^d \log[1 + (n-1)\lambda]
\end{aligned} \tag{37}$$

where $\hat{\Psi} = \theta(1 - \beta) - \frac{n}{N}(F + K) - c^1 + \alpha^h t + h - \beta$ and $\lambda \equiv e^{-\alpha^d t / \mu^d}$.

Following the same procedure for the case without trip chaining, the consumer surplus reduces to $\mu^d \log \left[n e^{\frac{h-p^*-\alpha^d t}{\mu^d}} \right]$ and $V_{i'nc} = \Xi + w^* - \beta - \alpha^w t + \mu^d \log[n] + h - p^* - \alpha^d t$.

This leads to the following expression for welfare:

$$W_{nc}(n) = \hat{\Psi} + (\mu^d + \mu^w) \log(n) - (\alpha^d + \alpha^w) t \tag{38}$$

where $\hat{\Psi}$ is defined above. Subtracting (38) from (37) we obtain

$$\begin{aligned}
W - W_{nc} &= \mu^d \log[1 + (n-1)\lambda] - \mu^d \log[n] + \alpha^d t \\
&= \mu^d \log \left[\frac{\lambda^{-1} - 1}{n} + 1 \right]
\end{aligned} \tag{39}$$

The right hand side of (39) is positive for $n \geq 1$ and t , α^d and μ^d all greater than zero, which are the model assumptions we specified.

REFERENCES

- Adler, T; Ben-Akiva, M E; (1979): A theoretical and empirical model of trip chaining behaviour. *Transportation Research Part B*, **13**, 243-257.
- Anderson, SP; de Palma, A; Thisse, JF (1992): Discrete Choice Theory of Product Differentiation. *MIT Press*.
- Axhausen, K; Zimmermann, A; Schönfelder, S; Rindsfuser, G; Haupt, T (2002): Observing the rhythms of daily life: a six week travel diary. *Transportation*, **29**, 95-124.
- Bhat, C et al (2004): Intershoppping duration: an analysis using multiweek data. *Transportation Research Part B*, **38**, 39-60.
- Bhat, C; Singh, SK (2000): A comprehensive daily activity-travel generation model system for workers. *Transportation Research Part A*, **34**, 1-22.
- Becker, GS (1987) Economic Analysis and Human Behaviour. *Advances in Behavioural Economics*, **1**, 3-17
- Bowman, J L; Ben-Akiva, M E (2001): Activity-Based Disaggregate Travel Demand Model System with Activity Schedules. *Transportation Research Part A*, **35**, 1-28.
- Brooks, CM; Kaufmann, PJ; Lichtenstein, DR (2004): Travel Configuration on Consumer Trip-Chained Store Choice. *Journal of Consumer Research*, **31**, 241-48
- De Palma, A; Dunkerley, F; Proost, S: (2004): Imperfect competition in a city with asymmetric subcentres in *Spatial Evolution and Modelling*, Nijkamp, P and Reggiani, A (eds), Edward Elgar, in press.
- De Palma, A; Proost, S (2005): Imperfect competition and congestion in the city. *ETE Working paper no. 2004-09*.
- Golob, TF (2000): A Simultaneous Model of Household Activity Participation and Trip Chain Generation. *Transportation Research: Part B*, **34**, 355-76.
- Haggett, P (1977) Locational analysis in human geography, Wiley, NY
- Hägerstrand, T (1970): What about people in regional science? *Papers of the Regional Science Association*, **24**, 7-21.
- Hägerstrand, T (1975) Space-time and human conditions in *Dynamic Allocation of Urban Space*, Karlqvist, A; Lindqvist and Snickars, F (eds), Saxon House, Westmead, 3-14.
- Hensher, DA; Reyes, AJ (2000): Trip Chaining as a Barrier to the Propensity to Use Public Transport. *Transportation*, **27**, 341-61.
- Kuppam, AR; Pendyala, RM (2001): A Structural Equations Analysis of Commuters' Activity and Travel Patterns. *Transportation*, **28**, 33-54.
- Recker, W W; Chen, C; McNally, M G (2001): Measuring the Impact of Efficient Household Travel Decisions on Potential Travel Time Savings and Accessibility Gains. *Transportation Research: Part A*, **35**, 339-69.