Collaborative Research: Design, Analysis and Implementation of Social Interactions in Cognitive Radio Networks

Husheng Li & Chien-fei Chen*

Department of Electrical Engineering & Computer Science;

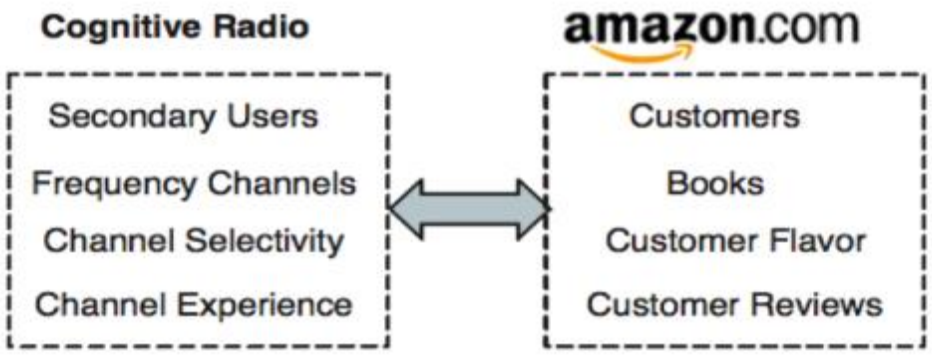
*NSF-DOE CURENT engineering research center

The University of Tennessee, Knoxville

Content

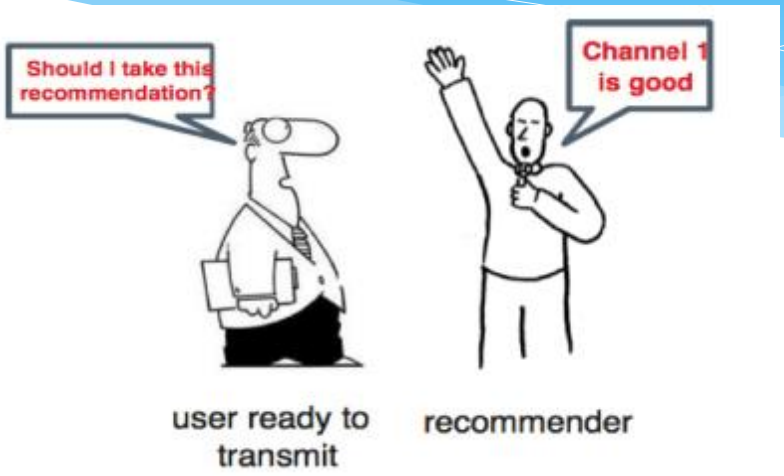
* Part I: Social network analysis of cognitive radio networks
* Part II: Exploring the impact of social-psychological and demographic factors on preference for speed over price and willingness to pay for a faster wireless service plan

Cognitive Radio Network As Social Network



* Each cognitive radio (CR) node can see (sense), think (compute) and talk (communicate), and thus can be considered as a person. A CR network can be considered as a society.
* Each CR node has a certain behavior, such as the preference of channel selection. Such a behavior affects the performance of each individual CR and the whole network.
* CR nodes can exchange their behaviors such as advertising their preference of channel selection. Hence, it is interesting and useful to study the behavior propagation in cognitive radio network.

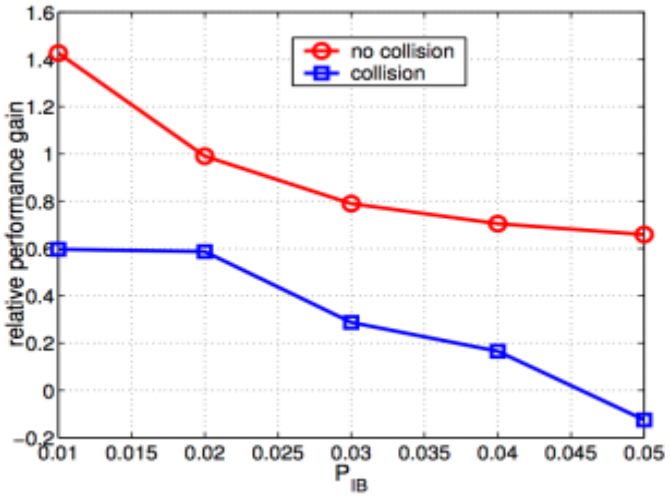
Based on Social Behavior Design: Recommendation



* We studied the recommendation mechanism, in which the CR nodes can exchange the information of their favorite channels.
* When a good channel emerges (e.g., the corresponding primary user has left), the information can be propagated through the CR network through the recommendation mechanism.

Performance Gain by Recommendations

* X. Chen, J. Huang and H. Li, ``Adaptive channel recommendation for opportunistic spectrum access,'' *IEEE Transaction on Mobile Computing*, vol. 12, no. 9, pp.1788—1800, Sept. 2013.
* Simulation shows that substantial performance gain can be achieved through this recommendation mechanism.



Collision: two users using the same channel causes transmission collisions.
X-axis: the busy level of channel
Y-axis: throughput gain over the case of no recommendations

Behavior Propagation

* Question: Suppose a good channel emerges (because a primary user has left); then, how fast can this information be propagated through the CR network?
* Similarity to epidemic propagation:
* Epidemic ←→ preference on this channel
* Infection ←→ adopt the recommendation of neighbor
* Social network ←→ CR network
* Recovery ←→ Discarding this channel

Mathematical Model of Behavior Propagation: ODE

* The transient dynamics of the behavior propagation fall in the are of non-equilibrium statistical mechanics. A precise description is based on the Master Equation.
* In our study, we used the mean-field dynamics (a.k.a Vlasov Equation) via the following ODE:

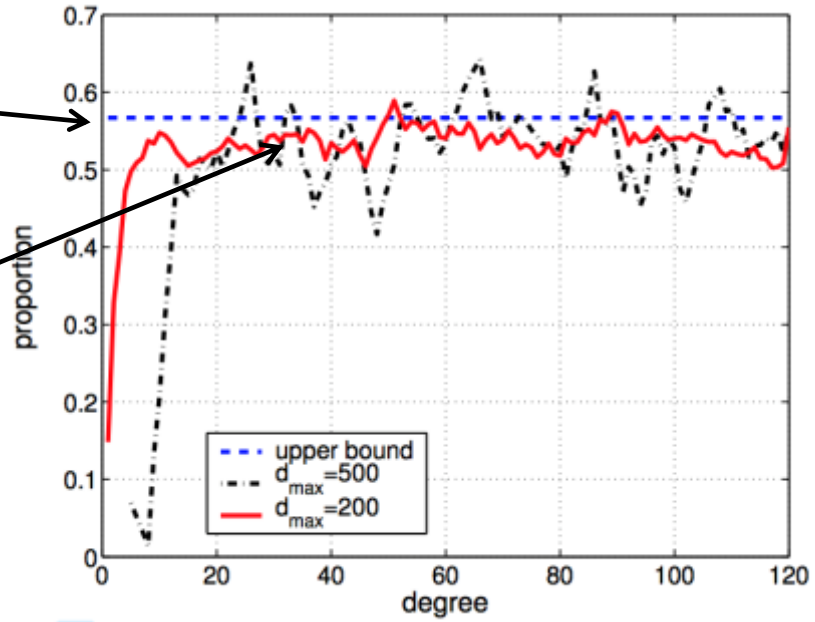
$$\dot{q}_k(t) = -\lambda q_k(t) + \mu\,(1 - q_k(t))\left(\phi + \sum_{n=1}^{\infty} q_n(t) P(m|k)\right)$$

where q_k is the proportion of CR nods with k neighbors using the corresponding channel, P(m|k) is the conditional index distribution, and λ, μ, ϕ are parameters characterizing the recommendation mechanism.

Results of ODE Modeling

Theoretical bound

Numerical results



* We obtained upper bounds for the percentages of CR users adopting the good channel with various degrees. They well match the numerical simulation results.

Mathematical Model of Behavior Propagation: Interacting Particles

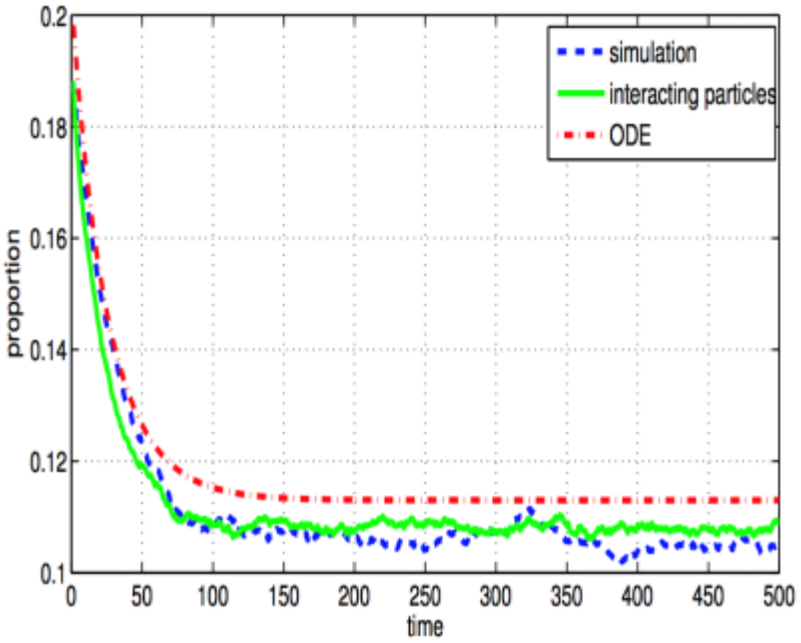
* We can also consider each CR node as a physical particle, which can interact with each other.
* We applied *the theory of interacting particles* in non-equilibrium statistical mechanics to study the behavior interactions in CR network.
* The equation of dynamics is given by

$$P\left[\eta_t(x) \neq \eta(x)|\boldsymbol{\eta}\right] = c(x, \boldsymbol{\eta})t + o(t),$$

Probability of Behavior change

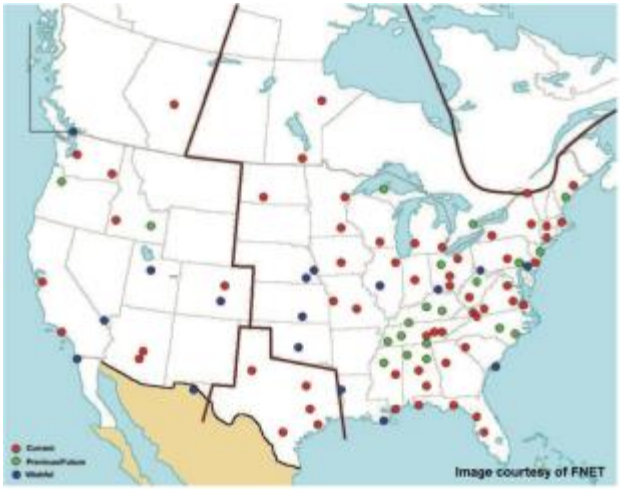
Impact of neighbors

Results of the Modeling of Interacting Particles

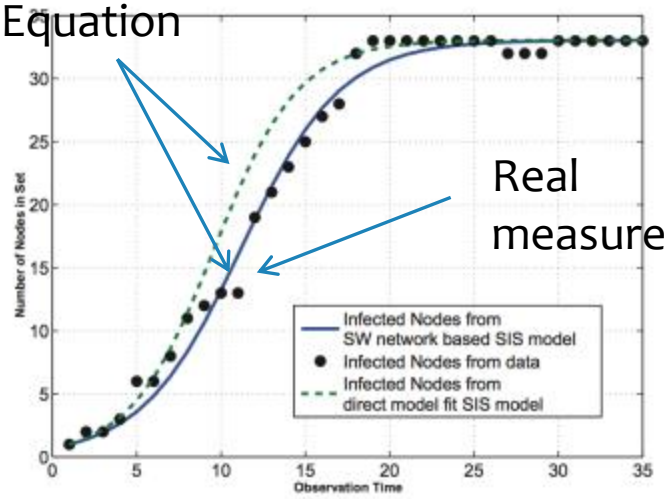


* The dynamics obtained from the interacting particles match the simulation results quite well.
* We also obtained the condition of ergodicity of the behavior dynamics via the interacting particle model.

Extension to Smart Grid



Epidemic Equation



Real measurement

* We also applied the mean-field equation of epidemic propagation dynamics to the frequency oscillation in power grids (H. Ma and **H. Li,** ``Analysis of frequency dynamics in power grid: A Bayesian structure learning approach,'' *IEEE Trans. on Smart Grid*, vol. 4, no.1, pp.457—468, March. 2013).

* We used the real measurements in US power grid and found that the equation can well describe the transient dynamics of frequency jump.

Future Work

* We will study other types of social interactions in CR network.
* We will consider the continuous-time and continuous-space approximation, which facilitates the application of diffusion dynamics.
* We will evaluate the performance gain of such social interactions in many other networking aspects.

Part II: Social-psychological Factors on Preference for Speed over Price and Willingness to Pay for a Faster Wireless Service Plan

* Standard economic models dominate marketing research on wireless communication networks
* Based on classical economics: individuals are rational; evaluate and pay for wireless services based on the utilities.

* Behavioral economics: people are irrational.
* Based on behavioral economics: Users' perceptions, feelings, and other social-psychological factors influence how they make decisions and are willing to pay for difference wireless services.

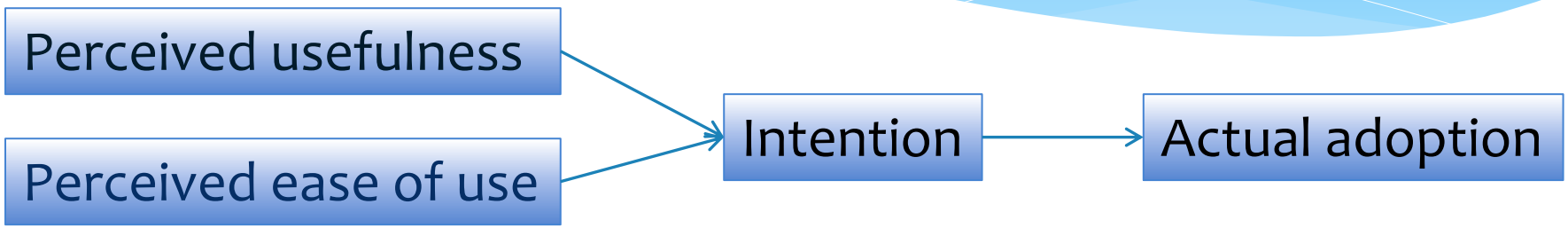
Goals of Our Study

* To test the impact of social networks on individuals' preference for speed over price and willingness to pay for a faster but a more expensive Internet service plan.
* To expand the technology acceptance model (TAM) on people's preference and willingness to pay for wireless technology by considering social-psychological and demographic factors.

Social Networks & Social Norms

* Social Networks: structural locations and positions influence others' behaviors (Wasserman & Faust, 1994)
* Injunctive norms: perception of what others approve
* Descriptive norms: perception of what others' actual behaviors (Cialdini, 1990)

Technology Acceptance Model (TAM)



Need for speed

Enjoyment

Computer self- efficacy

Education, income, political

Hypotheses

* H 1: Friends' preference for a **Faster** or a **Cheaper** Internet service → one's own decision in the same direction.

* H2a: Friends' preference for a **Faster** Internet service → **increase** in one's willingness to pay for a faster Internet service
  H2b: Friends preference for a **Cheaper** Internet service → **decrease** in one's willingness to pay.

Hypotheses

* H3: Social-psychological factors (e.g., perceived usefulness (PU), perceived ease of use (PE), expected enjoyment, computer self efficacy (CSE)) →on one's preference for a faster Internet service & willingness to pay for it.

* H4: Demographic factors → one's preference for a faster Internet service and willingness to pay for it.

Methods

* 400 U.S. residents were recruited from Amazon Mturk- an online crowdsourcing service.
* Online experiment (H1, H2) and survey (H3, & H4)

* 281 valid responses

50.9% males, 47.7% females; average age = 33.93.

76.51% received at least some college education;

43.06% with annual income >$50,000.

56% indicated liberal or strong liberal political orientation.

Experimental Design

* "Imagine themselves as currently paying ***$2 per day*** for a ***12Mbps*** Internet service plan. With this speed, you could download a full-length HD movie (1GB size) in 2.5 hours. …"
* "***-- Option I: 18Mbps –***
  You could download a full-length HD movie (1GB size) in 1.5 hours.
  Would you consider this plan? Yes No
  I would like to pay ____dollars per day for the service.
* ***-- Option II: 6 Mbps –***
  You could download a full-length HD movie (1GB size) in 4 hours.
  Would you consider this plan? Yes No
  I would like to pay ____dollars per day for the service.
* ***-- Option III …***"

Experimental Conditions

* **Condition 1-** friends prefer faster plans
* **Condition 2-** friends prefer cheaper (but slower) plans
* **Condition 3-** no information about friends' preference.

Results – Impact of Friends' Preferences

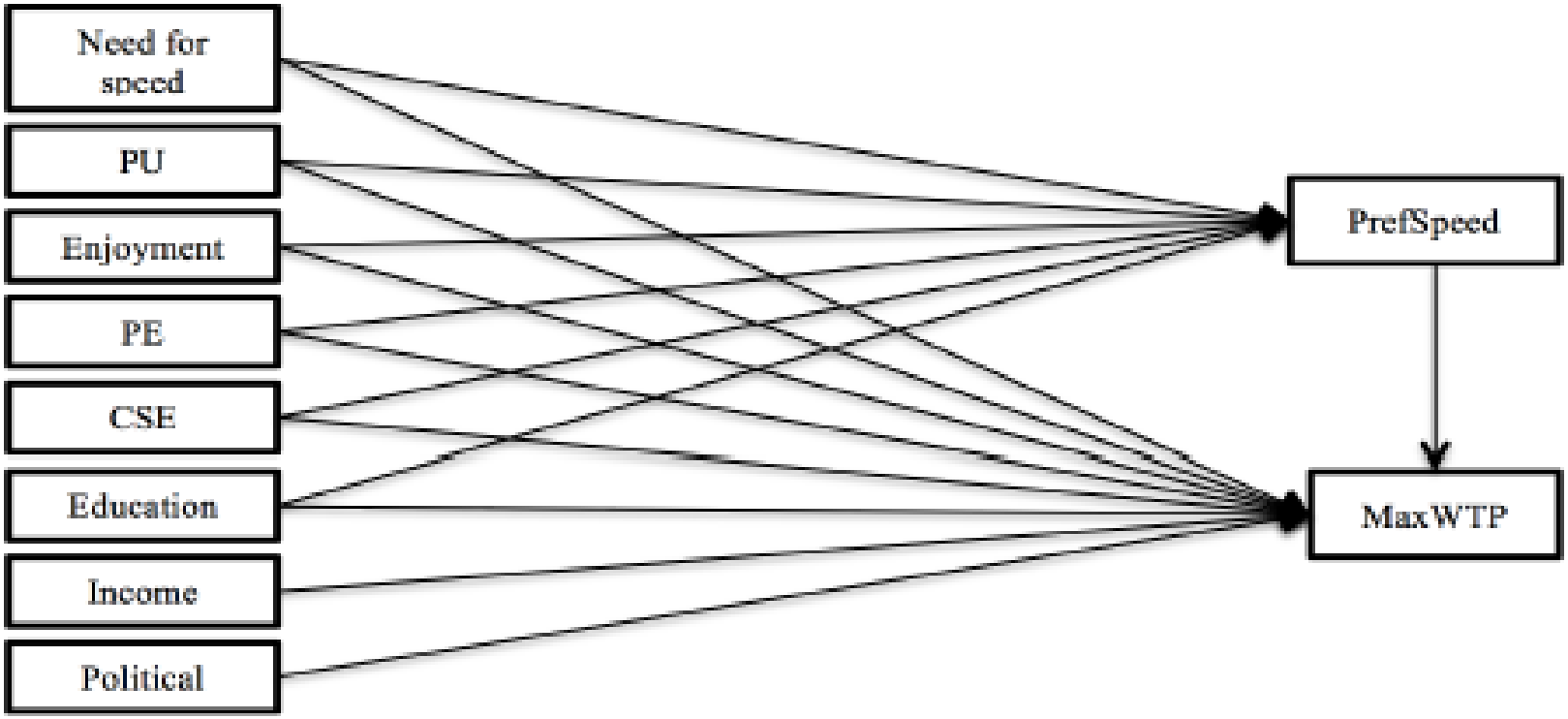
Condition	Variable	N	Mean	S.D.
1. Friends prefer high speed	MaxWTP	98	4.10	2.11
	PreSpeed	97	58.28	21.16
2. Friends prefer low price	MaxWTP	75	3.40	1.74
	PreSpeed	75	51.72	18.84
3. Control	MaxWTP	107	4.04	2.30
	PreSpeed	107	55.77	21.34

$p = .021$

$p = .036$

Methods – Survey

* Survey questions revolving around variables by expanding TAM model



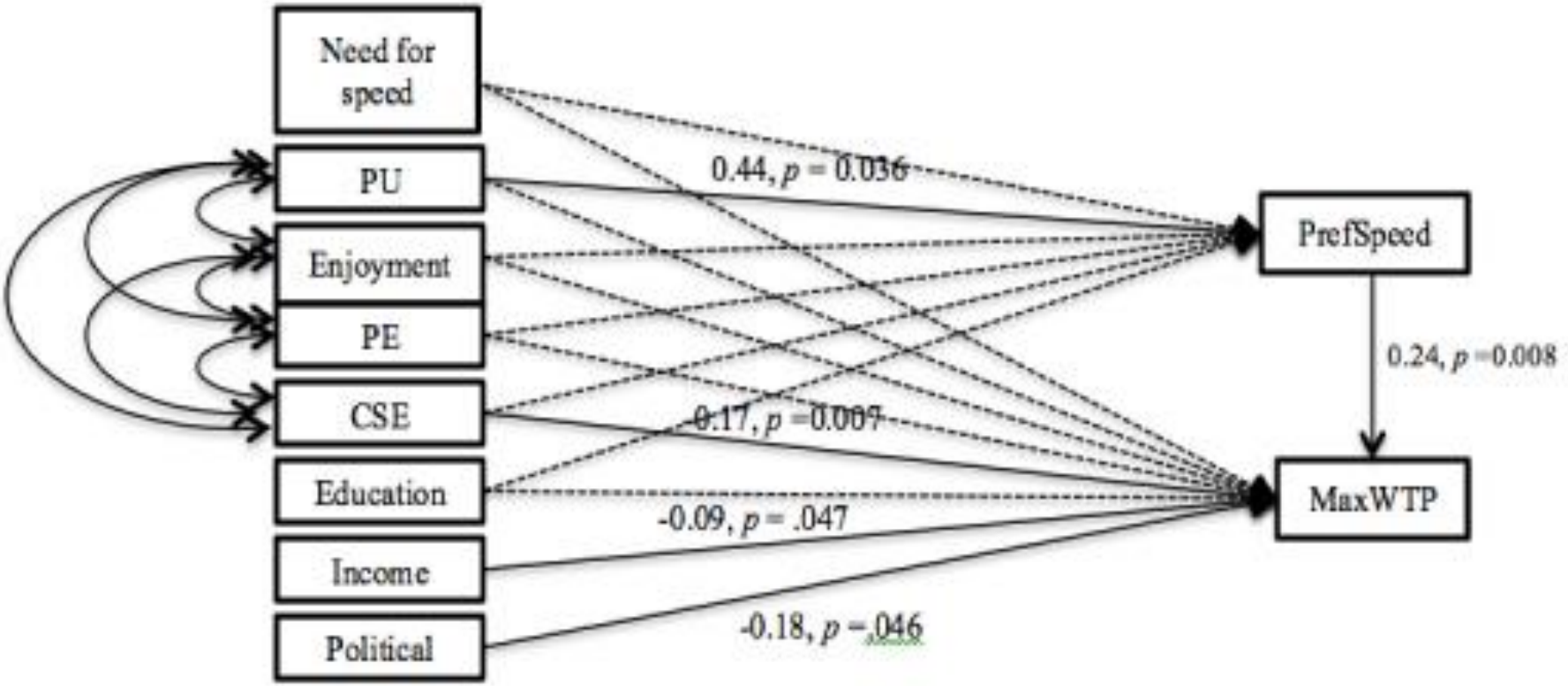
Methods – Survey Measure

* Example of the measure of perceived usefulness (PU):

* I find Internet useful in my daily life
* Using Internet helps me perform many things more conveniently
* Using Internet helps me accomplish things more quickly
* Using internet increases my productivity

* 1 strongly disagree – 2 disagree – 3 somewhat disagree – 4 neutral – 5 somewhat agree – 6 agree – 7 strongly agree

Survey Results



Conclusions

* People are irrational.
  * Standard economic models are not sufficient.
* Social influences (e.g., friends' opinions) matter.
  * Friends' preference for a slower but cheaper Internet service → reduced reference for faster services and willingness to pay
* Psychological variables are involved.
  * Perceived usefulness and computer self efficacy affected participants' preference for speed and willingness to pay
* Demographic variables are important.
  * People with a stronger liberal orientation indicated higher willingness to pay for a faster Internet service plan.

References

* X. H., C. F. Chen, W. Gao, and H. Li. “Beyond Classical Economics: Exploring the Impact of Social-Psychological Factors on Preference for Speed over Price and Willingness to Pay for a Faster Wireless Service Plan,” *Proceedings of the IEEE/CIC International Conference on Communications in China* (ICCC), August, 2013.