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Co-evolution of three mega-trends nurtures un-captured GDP – Uber's ride-sharing revolution

Chihiro Watanabe [a, b, *], Kashif Naveed [a], Pekka Neittaanmäki [a]

[a] University of Jyväskylä, Finland
[b] International Institute for Applied Systems Analysis (IIASA), Austria

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ABSTRACT

Uber used a disruptive business model driven by digital technology to trigger a ride-sharing revolution. The institutional sources of the company's platform ecosystem architecture were analyzed to explain this revolutionary change.

Both an empirical analysis of a co-existing development trajectory with taxis and institutional enablers that helped to create Uber's platform ecosystem were analyzed.

The analysis identified a correspondence with the "two-faced" nature of ICT that nurtures un-captured GDP. This two-faced nature of ICT can be attributed to a virtuous cycle of decline in prices and an increase in the number of trips.

We show that this cycle can be attributed to a self-propagating function that plays a vital role in the spinoff from traditional co-evolution to new co-evolution. Furthermore, we use the three mega-trends of ICT advancement, paradigm change and a shift in people's preferences to explain the secret of Uber's system success.

All these noteworthy elements seem essential to a well-functioning platform ecosystem architecture, not only in transportation but also for other business institutions.

1. Introduction

The dramatic advancement of information and communication technology (ICT) in recent years has brought about a new reality in which information, people, organizations, logistics, and finance are constantly connected on a global level and mutually influence one another. This constant connection is starting to produce a hitherto non-existent synergy without being bound to the confines of existing industrial structure and technology fields. Therefore, the synergy allows the creation of new businesses and markets, and is also starting to change how we work and live (Council of Science, Technology and Innovation, 2016) [9].

Uber, an on-demand ridesharing service that connects passengers to local drivers in real time using smartphone technology, demonstrates this ICT-driven disruptive business model by triggering a ride-sharing revolution.

In light of its conspicuous accomplishment, to date, considerable studies have been undertaken in elucidating, conceptualizing and operationalizing Uber's system success. The studies can be classified into five streams: (i) prospect of automotive industry, (ii) ride-sharing revolution, (iii) disruptive innovation, (iv) ICT-driven innovation, and (v) new business model.

Schlze et al. (2015) [24] pointed out that automotive firms cope with turbulence caused by globalization, new government regulations, and advances in electronics, communication, and drive train technologies. In the mean time, these technologies are facilitating not only new product features but also new business models which Uber deployed as consumer preferences move toward mobility as a service rather than vehicles as products. They stressed the significance of a wide lens (Adner, 2012) [1] with change and stability. Avital et al. (2014) [2] stressed that an economy based on the exchange of capital, assets and services between individuals has grown significantly, spurred by the proliferation of Internet-based platforms that allow people to share underutilized resources and trade with reasonable transaction costs. The movement to the ride-sharing revolution triggered by Uber was also postulated by Blk (2014) [5], Koopeman et al. (2014)

* Corresponding author. University of Jyvaskyla, Finland.
E-mail addresses: watanabe.c.pqr@gmail.com (C. Watanabe), kanaveed@student.jyu.fi (K. Naveed), pekka.neittaanmaki@jyu.fi (P. Neittaanmäki).

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0160-791X/

Table 1
Parallel Paths between history of Uber and ICT advancement.

Year	Uber's Story	Advancement of ICT
2008 Winter	The story of Uber in Paris	Apple's iPhone (2007), Google's Android (HTC)
2009 March	UberCab (renamed to Uber in 2011) was established in SF	Many new smartphone models and OS launched.
2010 July	**UberCab** (on-demand car service via an iPhone app or SMS (short message service)) released in SF.	Apple iPad tablet, Instagram was founded.
2011 May	Expanded into a new city each month including NYC, Chicago and Washington DC	3 Billion Android downloads,
Dec	In operation in Paris (first outside of the US) Raised 44.5 m US$	Tablet pc's by Samsung, Sony, Acer, etc.
2012 July	**UberX** (low cost Uber: for-pay rideshare scheme, trips cost less than the same journey in an ordinary taxi)	Android and iOS dominated the market share. US smartphone sales passed featured phone sales.
2013 Summer	Faced competition from ride-sharing services like Lyft Experimental Uber Chopper (helicopters transporting service)	85% of US adults use the Internet, 2 Million apps, U.S. consumer spends 126 min per day on Mobile apps compared to 168 min on TV
2014 April	Banned by the government in Berlin	In person, Mobile payments in the US doubled to $3.7B
June	Taxi drivers in London, Paris, and Madrid staged a large-scale protest	59% of US smartphone owners do mobile shopping.
August	**UberPool** (matching passenger with another rider heading in the same direction)	Since 2010 the Digital media time spent on
October	Received an "F" (flunk) rating from the Better Business Bureau (BBB)	Smartphone increased by 394% and tablets by 1721%
November	**Uber Go** (officially the cheapest ride in town)	Both platforms account for 60% of total time spent.
2015 Feb	Established Uber Advanced Technology Center (collaboration with Carnegie Mellon)	78% of US mobile subscribers owned a smart phone.
April	UberEATS program (food delivery service)	US consumers spend 4.7 h on average on smartphone each day.
May	Uber Military Families Coalition, App accommodating for drivers for deaf or hard of hearing 58 countries and 300 cities	U.S. consumer now spends 198 min per day on Mobile apps compared to 168 min on TV
2015 Dec	Market value 62.5 B US$	U.S. has the highest average rate of monthly data consumption via smartphone: a colossal 20 GB.

[17], King (2015) [16] and Ehret (2015) [11]. Ehret referred Rifkin's "Zero marginal cost society" (Rifkin, 2014) [23] and suggested uncaptured GDP (Watanabe et al., 2016) [36] that Uber may emerge by stressing that "*Soon we will have access to most products and services at almost no marginal cost. Mega-corporation will cease to make profits and the capitalist market economy will be replaced by a collaborative commons, where people exchange ideas and support each other with creative solutions*."

This emerging paradigm is disruptive to the conventional company-driven economic paradigm as evidenced by a large number of peer-to-peer based services (Avital et al., 2014) [2] on which Uber is based. Isaac et al. (2014) [15] appreciated Uber as one of the most disruptive, successful tech start-up company which has severely disrupted the taxi service industry. They pointed out that much of the success Uber has generated so quickly relies on (i) its ability to classify itself as a "technology company" instead of a transportation company, (ii) the ability to classify their drivers as independent contractors instead of employees, and (iii) a depressed market in which workers are willing to assume the burden of risks and costs associated with driving for the company. They pointed that much of the reason why Uber has been so threating to the traditional taxi industry lay in its efficient and innovative utilization of modern technology, particularly ICT. Baiyere et al. (2015) [4] supported this view by stressing that rapid continuous advancement in ICT corresponds to the emergence of disruptive ICT innovation increases. Horpedahl (2015) [14] highlighted smartphone apps are stressing that they allow consumers to bypass traditional taxicabs. All led to a new business model. Cohen et al. (2014) [7] reminded that some altogether new and different business has emerged over the several past years. These developments have started to challenge traditional thinking about how resources can and should be offered and consumed. This way of thinking supports the arguments that incremental improvements in our existing production and consumption systems are insufficient to transform our global economy toward sustainability (Lovins et al., 2011 [18], Stead et al., 2013 [26]). From these, a new business model inevitably emerges toward the shared economy. Cohen et al. (2014) [7] pointed out that shared mobility solutions can be attributed to multiple agents, including public and private providers, seek to develop business models which address deficiencies in public infrastructure and public transit systems, historically the exclusive purview of local and regional governments. They also warned that the common interest in sustainability among these different types of agents does not always lead to harmony, instead giving rise to agency conflicts that can reduce the positive sustainability impact of their individual and collective initiatives. Indeed, Uber has been confronting legal battles with the traditional automotive industry, particularly the taxi industry in some countries.

All the preceding streams intertwine with each other leading to a new system design or systems web. Uber's system success and ICT-driven disruptive business model, on which Uber is based, can be attributed to a co-evolution of this systems web. However, scholars have yet to undertake an analysis of a co-evolution of a systems web which connects these new streams.

Inspired by noting the contrast between the world's leading ICT countries with respect to happiness/welfare amidst great stagnation in Finland and conspicuous economic growth in Singapore, authors have demonstrated that current ICT-driven global development depends on a trend shifting from traditional co-evolution of computer-initiated ICT, captured GDP, and economic functionality to new co-evolution of the Internet, un-captured GDP, and supra-functionality beyond economic value. The authors then demonstrated that the above contrast can be attributed to the difference between the two states in the shifting trends described above (Watanabe et al., 2016) [36].

This paper elucidates and conceptualizes Uber's system success based on Uber's contrasting disruptive innovation development trajectory and contrasts the ICT-driven disruptive business model with the traditional taxi industry based on a traditional business model. An empirical analysis similar to the analysis done on the co-evolution of three mega-trends governing the difference of the state in the shifting trends was conducted.

Section 2 reviews Uber's conspicuous start-up. Section 3 analyzes institutional enablers creating platform ecosystems. Section 4 demonstrates co-evolution of three mega-trends leading to sharing economy. Section 5 briefly summarizes noteworthy findings, implications, and suggestions for future works.

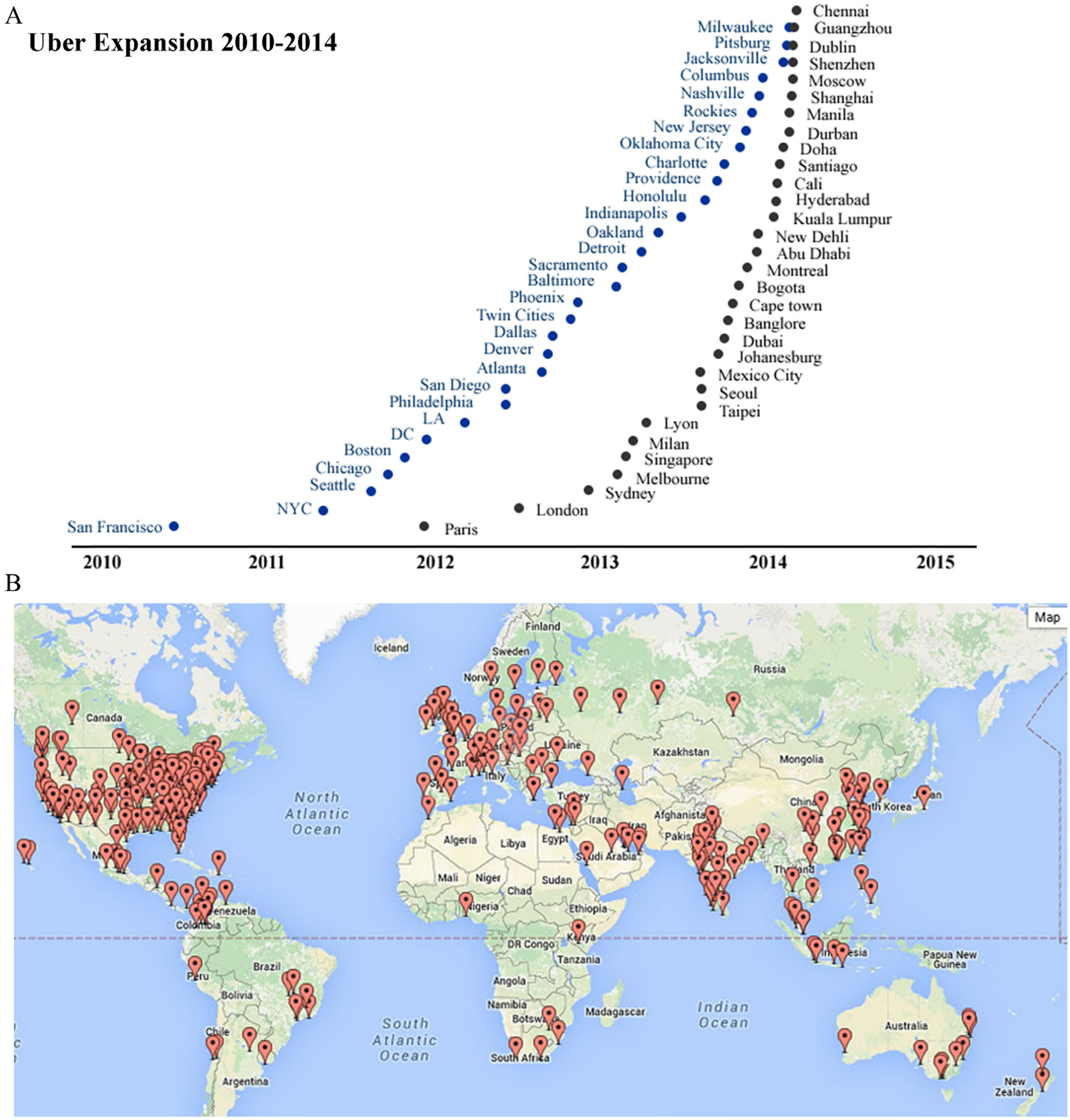


Fig. 1. A. Uber's expansion trajectory worldwide (Source Uber.com). B. Uber's expansion in 375 cities on world map *(as of Jan. 2016)* (Source: Author's geocoded map based on Uber's cities list at Uber.com (see Appendix 5)).

2. Uber, its conspicuous start-up

2.1. Digital technology driven disruptive business model

Ride-sharing company Uber is a high-tech company founded in March 2009 (Table 1). It is seen as the jewel of ICT as it brilliantly connects the transportation industry with ICT via its ride-sharing application and it leverages the sharing revolution (Belk, 2014) [5], leading to the transformation of the market for taxi cabs and limousines. It offers its service in over 375 cities worldwide in 2015 (Fig. 1A, B). Uber is regarded as the highest-valued venture-supported company. It is currently one of the fastest growing start-ups worldwide. It's value exceeds the value of the full US taxi and limousine industry.

Uber gives passengers a better service with cost and time savings in reaching a location, and it provides its drivers with a highly efficient operation without additional investment and license fees (Table 2). Its system is convenient also for drivers. They can work flexible hours and can reject unwanted clients.

Through a cashless system based on credit cards, Uber can trace and choose highly-rated drivers. Reliance on digital technology provides passengers with a transparent view of quality and prices. Similarly, drivers can memorize passenger's behavior. Thus, Uber has established a mutual rating system among the company, drivers, and passengers.

In this way, Uber has triggered a disruptive business model which is driven by digital technology. This technology has been significantly impacting traditional business, not only in transportation but also almost all business institutions.

Uber appraised itself for this business model as "*Uber epitomizes*

Table 2
Competitive analysis between Uber and taxi.

	Uber	Taxi	Remarks (Uber's unique advantage)
Advance booking	No	Yes	
Hiring method	Smart phone App	Flag/Call center/App/Dedicated taxi queue	
Payment	Cashless	Cash/Credit card	
Driver/Passenger rating	Available	NA	Co-evolution by mutual rating system
Pricing structure	Premium principle Flexible Surge pricing	Cost principle Structured	Customers pay for services for reliable, punctual, comfortable Clear overview of price before booking Respond to changes in supply and demand in the market
Fare sharing	Anyone	Limited to friends	
ETA to destination	Available	NA	Estimated Time of Arrival. Follow drivers on map
ETA of the ride	Available	Available (Apps only)	One-tap ride
Car	Self	Rented from taxi company	
Driver's perspectives	Flexible and independent	Rigid	Motivation why drivers choose Uber (Bureau of Labor Statistics)
Law and regulation	Gray area	Well defined	
Value capture to company	Commission fee	Rental fee, Advertisement	91%: Earn more income, 87%: To be my own boss, 85%: flexible and balancing with a better life.

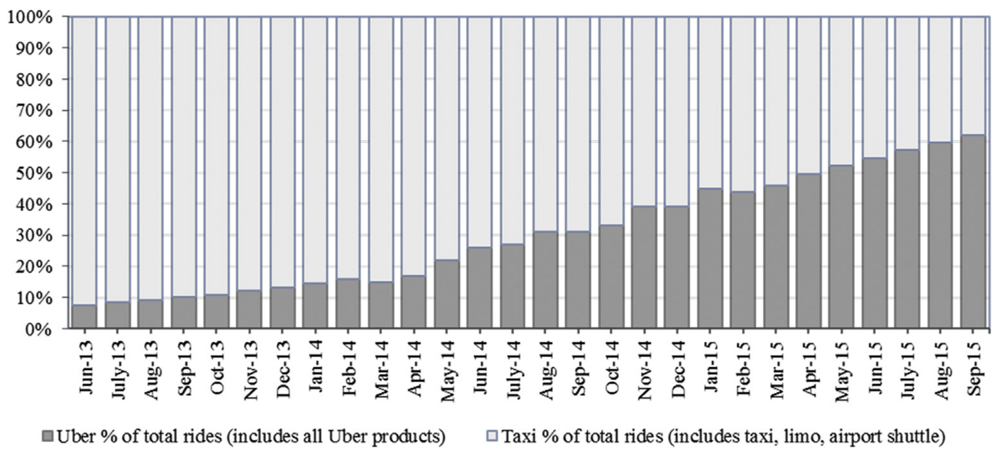


Fig. 2. The trend in share of rides by Taxi and Uber in the US *(Jun. 2013 – Sep. 2015)*.
Sources – Jan. 2014–Mar. 2015: Certify (2015) [6], other periods: authors' estimate based on TLC and Uber (See Appendix 1).

disruption. The company has changed the way we think about grabbing a ride, incorporating the same technology we take for granted today into a brand new experience for consumers and an opportunity for producers" (A Brief History of Uber) [29].

2.2. Astounding rise

As a general consequence of the numerical analysis of newly emerged innovation, elucidation of Uber's systems success was a challenge in exploring the dark continent without published statistical data.

Fig. 2 attempts to trace the trajectory of Uber's astounding rise. Conspicuousness of Uber's disruptive business model can be confirmed by the astounding rise in the number of its users. Based on expense reports from business travelers, Certify (2015) [6] revealed that an average 46% of all total paid car rides were through Uber in major markets across the US in March 2015. This demonstrates a steep rise particular in business use over the 14 months from a mere 15% in January 2014 as demonstrated in Fig. 2.

Uber's fast rise to success directly correlates with the decrease in the number of traditional taxi users. The share of taxi, limousine and shuttles of that number fell dramatically from 85% to 54% over this 14 months. This observation is rather biased towards Uber, as the report is focused on business travelers, it has been estimated that the number of people using Uber is higher than the number of people using a taxi now (Frier, 2015) [12].

2.3. Trend in the substitution for taxi

(1) Trends in Taxi Revenues, Trips and Prices (Jun. 2013–Sep. 2015)

Fig. 3-A –C demonstrate trends in taxi revenues, trips and prices in NYC over the period June 2013–September 2015.

As a consequence of Uber's astounding rise in a co-existing development trajectory with taxis, the number of trips in taxis demonstrates rapid decline (Fig. 3–A) which resulted in their revenues decline (Fig. 3–B) and subsequent increase in their prices (Fig. 3-C).

(2) Comparison of the Trends in Trips and Prices between Uber and Taxi

Fig. 4 demonstrates trends in Uber and taxi trips in NYC over the period June 2013–September 2015. Similarly, Fig. 5 demonstrates trends in Uber and taxi prices in NYC over the same period.[1]

[1] This analysis focuses on the state in NYC as it demonstrates pioneer state of ridesharing revolution in the US (Hickman, 2015 [13]; Silverstein, 2014 [25]; Stone, 2015 [4]), and all data in Figs. 4 and 5 are based on the state in NYC, except Uber share (U_D) in estimating Uber trip (U_T) in Fig. 4. Due to unavailability of reliable statistics on U_D in NYC, it based on the average Uber share in the US focusing on business use (Fig. 2) which should be interpreted slightly reserved to Uber trips in NYC.

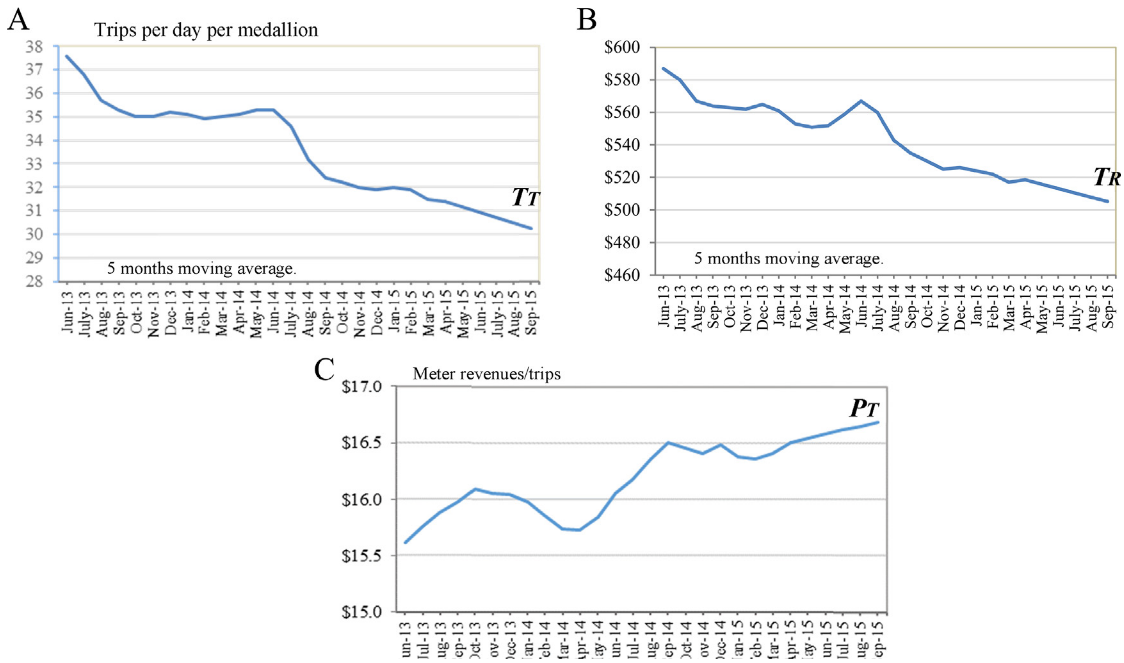


Fig. 3. A. Trend in taxi trips in NYC *(Jun. 2013 – Sep. 2015)*. B. Trend in meter revenues in NYC *(Jun. 2013 – Sep. 2015)*. C. Trend in taxi prices in NYC *(Jun. 2013 – Sep. 2015)*.
Sources: *TR* and *TT*- Jun. 2013–Mar. 2015: Hickman (2015) [13] based on NYC Taxi and Limousine Commission (TLC), another period: authors' estimate based on TLC. $PT = TR/TT$ (See Appendix 1).

At the same time as Uber's astounding success, Uber's prices continued to decline and in May 2014 they reached the same level as taxis. The prices further declined with the introduction of UberPool in August 2014. The decline in prices was reversed as a consequence of Uber's surge pricing, and resulted in an "F" (flunk) rating from the Better Business Bureau (BBB) in October 2014 when complaints about unexpectedly high charges were cited. In response to such complaints and also to competition from competitors such as Lyft, Uber managed to decrease prices by introducing Uber Go in November 2014. This move, together with technology advancement effort by the establishment of the Uber Advanced Technology Center in February 2015, led to lower prices again in 2015.

3. Institutional enablers leveraging Uber's astounding rise

3.1. Sharing economy for physical products

Uber's astounding rise can largely be attributed to dissemination of sharing economy from digital products to physical products.

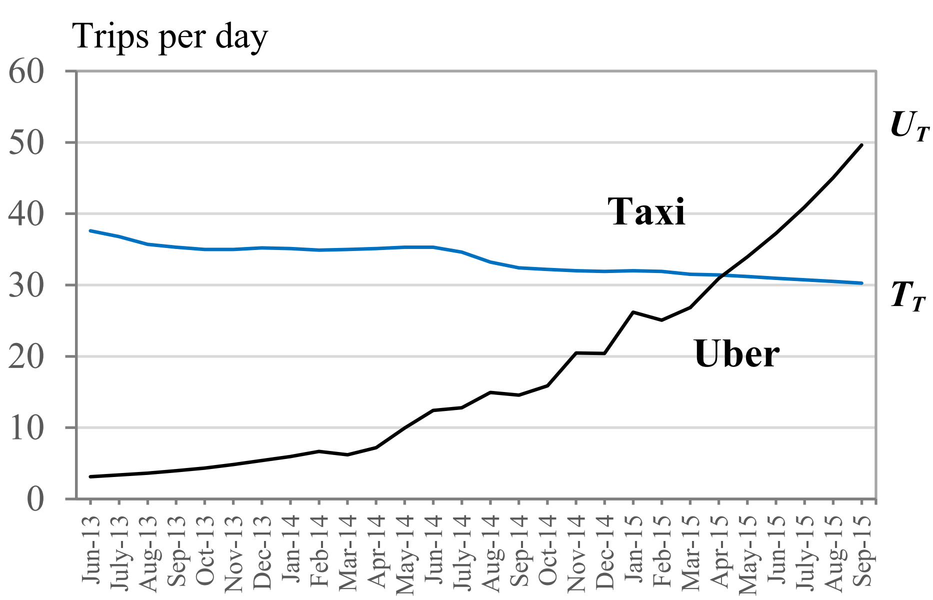


Fig. 4. Trends in Uber and taxi trips in NYC *(Jun. 2013 – Sep. 2015)*.
Sources – Taxi: Fig. 3–A. Uber: authors' estimate based on $U_T = \frac{U_D}{1-U_D} \cdot T_T$ where U_T: Uber trip, T_T: Taxi trip, U_D: Dependency on Uber (share of Uber trips out of sum of Uber and taxi trips as demonstrated in Fig. 2) (See Appendix 1).

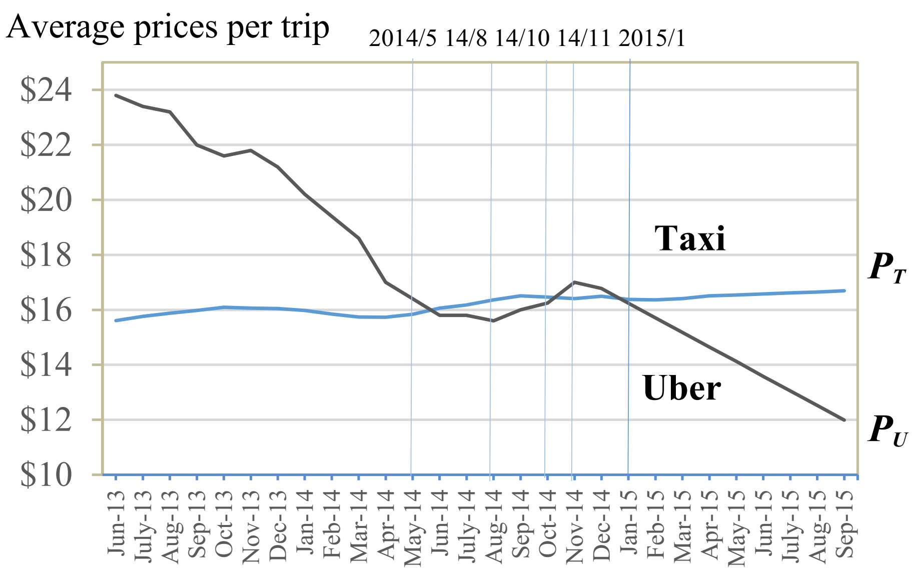


Fig. 5. Trends in Uber and taxi prices in NYC *(Jun. 2013 – Sep. 2015)*.
Sources – Taxi: Fig. 3-C, Uber – Jun. 2013–Nov. 2014: Lunden (2014) [20], other period: Authors 'estimate based on TLC, Uber, Stone (2015) [27] and Silverstein (2014) [25] See Appendix 1).

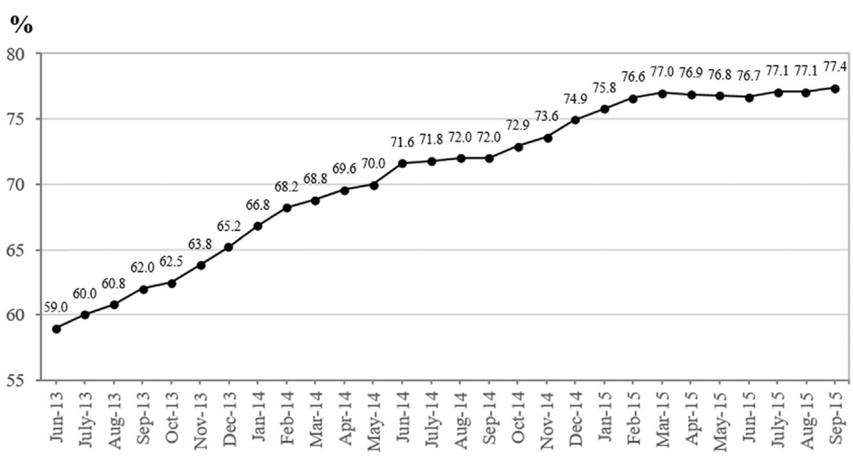


Fig. 6. The trend in smartphone share in the US mobile subscriber market *(Jul. 2013 – Sep. 2015)*. Smartphone share of the US mobile subscriber market: % of mobile subscribers aged 13 + owning a smartphone.
Source: comScore (2013–2015) [8].

Table 3
Governing factors of Uber prices in NYC *(Jun. 2013 – Sep. 2015)*.

$$\ln P_U = 6.361 - 0.717\, D_1 \ln SP - 1.015\, D_2 \ln SP - 0.551\, D_3 \ln SP - 0.213\, D_1 \ln U_T + 0.278\, D_2 \ln U_T - 0.376\, D_3 \ln U_T \qquad adj.R^2\ 0.980 \qquad DW\ 1.25$$

$$(4.06^{*1}) \quad (-1.80^{*4}) \quad (-2.62^{*2}) \quad (-1.49^{*5}) \quad (-3.63^{*1}) \quad (2.52^{*2}) \quad (-10.84^{*1})$$

D_1: 2013.6 – 2014.7 = 1, rest = 0. D_2: 2014.8 – 2014.11 = 1, rest = 0, D_3: 2014.12 – 2015.9 = 1, rest = 0.
Figures in parenthesis indicate t-statistics: significant at $*^1$:1%, $*^2$:2%, $*^4$:10%, $*^5$: 15% level.

Table 4
Contribution of Uber prices decrease in NYC *(Jun. 2013 – Sep. 2015)* – % p.a.

PU decrease $\frac{\Delta P_U}{P_U}$ rate	Contribution by			Period
	SP increase rate	U_T increase rate	Miscellaneous	
−3.07	−0.717 × 1.52 = −1.09	−0.213 × 11.92 = −2.54	0.56	2013/6–2014/7
1.87	−1.015 × 0.62 = −0.63	0.278 × 13.02 = 3.62	−1.12	2014/8–2014/11
−3.43	−0.551 × 0.51 = −0.28	−0.376 × 9.57 = −3.60	0.45	2014/12–2015/9

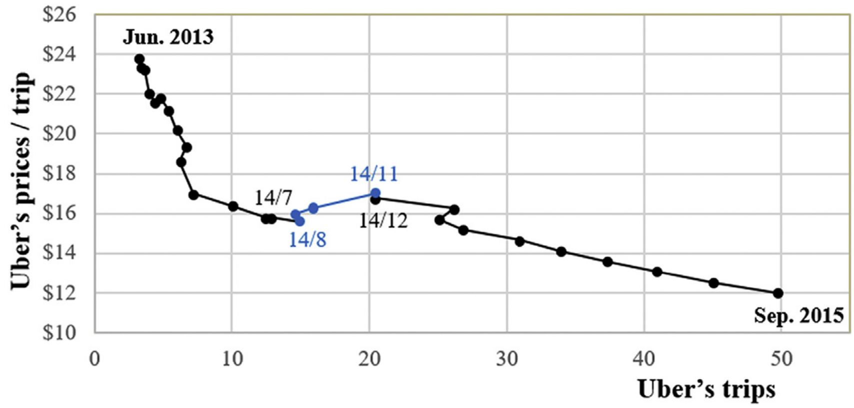


Fig. 7. Correlation between Uber's trips and their prices in NYC *(Jun. 2013 – Sep. 2015)*.

In line with people's preferences shift from economic functionality to supra-functionality beyond economic value (Watanabe et al., 2014 [34]), sharing economy in physical products (i.e., rooms and cars) has been gaining momentum.

The underlining paradigm of the original sharing economy is that users aim at increasing resource-use efficiency, to lower costs or to create new value. Online trading platforms such as Napster and eMula were amongst the first to provide users with shared access to digital music and videos. It was possible to download these digital products from lenders on the platform for free, and uploading and downloading happened simultaneously (Winterhalter et al., 2015 [37]).

People's preference shift to supra-functionality has led to requests for a similar platform also for physical products. People wish to use such products (which were provided passively, primarily with economic functionality) in a more sophisticated manner by their initiative (Adner, 2012 [1]).

Sharing economy for physical products initiated by Uber and AirbnB is needed by the market with such underlining paradigm.

3.2. *Institutional enabler of sharing economy in physical products*

(1) Advancement of ICT

The main enablers of the sharing economy are ICT and Internet connectivity, which allow effective peer-to-peer contact (The Economist, 2013 [28]).

Thanks to the dramatic advancement of the Internet, countless websites connect people on a peer-to-peer basis with separate resources of almost any kind (not only time, digital information and knowledge resources but also space and fixed assets) to the needs of others searching for these resources.

Such advancement, particularly of a smartphone, nurtures Uber by enabling high qualified services with lower cost[2] and shorter time. Fig. 6 demonstrates a trend in smartphone share in the US mobile subscriber market over the period July 2013–September 2015. Looking at Fig. 6 we note that while smartphone has gained popularity, and its share in the mobile subscriber market demonstrated a sharp increase in the US, there has been stagnation in the upward surge and a shift from quantity to quality in 2015 in nationwide in the US (comScore, 2013–2015 [8]).

(2) Passengers Initiative and Paradigm Shift to Ecosystem

Passengers initiative also strengthens, while the company's systematic market strategy brings benefits such as continuous reductions in costs and time for search and matching while eliminating information asymmetries and compiling a massive database.

Uber compiles a massive database on driver and rider behavior, which is essential to Uber price-setting and market-making. Also, it allows Uber and the regulators to ensure safety and to root out discrimination against passengers.

In addition to the introduction of the Internet, the paradigm shift from resources to ecosystem (from captured GDP to uncaptured GDP (Watanabe et al., 2014, 2015 [34,35]) has been leveraged by Uber in its creation of a new business. Shifting from traditional in-house-oriented business towards services making use of interactions between the stakeholders: company, drivers, and passengers.

Under the support of these institutional enablers, Uber was able to accomplish astounding rise by the following simple business model:

(i) Its smartphone-based app connects drivers, offering rides and passengers seeking them,
(ii) Passengers pay mileage-based fees through credit cards that company keeps on file, and
(iii) Uber takes a percentage of each fee and gives the rest to its driver.

3.3. *Self-propagating virtuous cycle*

(1) Governing Factors of Uber Prices Decline

Since Uber prices (P_U) are governed by the increase in smartphones demonstrated by its share in the mobile subscriber market (*SP*), learning and economy of scale effects, their trend can be

Table 5
Estimates of Medallion prices for the period preceding their stagnation (Jan. 2004–Jun. 2013).

	$Y = \frac{N}{1+be^{-at}}$		
	Estimate	*t-value*	*adj. R^2*
N	2247.11	7.23	0.976
a	0.02	14.21	
b	6.36	7.21	

Y: Medallion prices, *N*: Carrying capacity, *t*: Monthly trend, *a*, *b*: Coefficients.
All t-values demonstrate statistically significant at the 1% level.

[2] e.g., from downtown L.A. to the airport (Uber: 22 US$, Taxi: 46.5 US$ (56 $ with 20% tip)) in 2015.

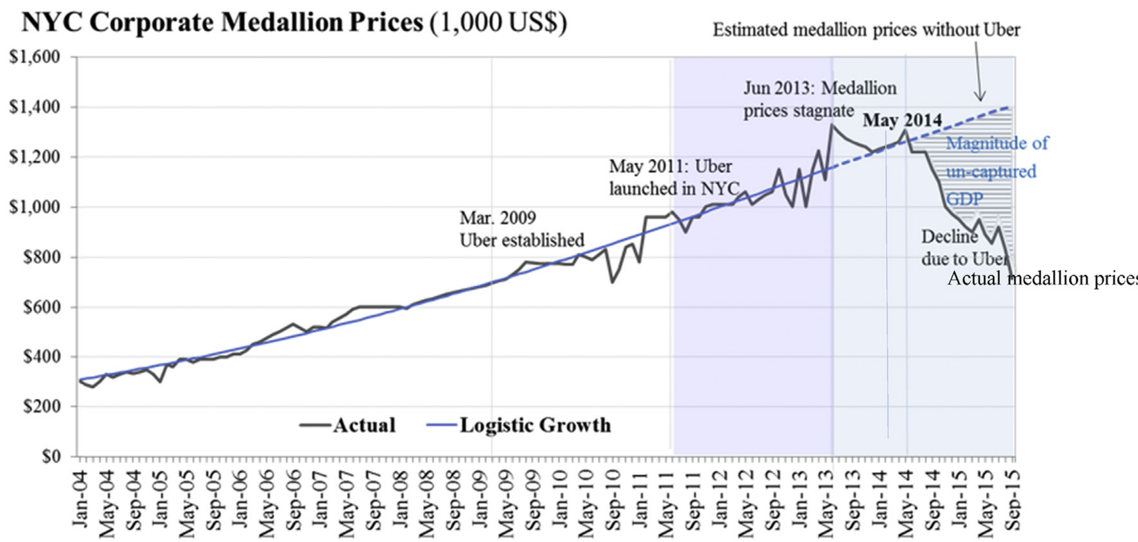


Fig. 8. Trends in corporate Medallion prices and their estimate without Uber in NYC – 2013 prices (Jan. 2004–Sep. 2015).
Source: NYC Taxi and Limousine Commission (TLC).

depicted as follows:

$$P_U = A \cdot SP^{\alpha} \cdot U_T^{-\lambda}$$
$$\ln P_U = \ln A + \alpha \ln SP - \lambda \ln U_T$$

A: scale factor, U_T: Uber trips, α :SP elasticity to P_U, and λ : learning coefficients (learning and economy of scale effects).

Based on this equation, Table 3 identifies governing factors of Uber prices in NYC over the period June 2013–September 2015 by dividing into three periods: 2013/6–2014/7 (sharp decline), 2014/8–2014/11 (change to increase due to surge pricing), and 2014/12–2015/9 (decline by introducing Uber Go and technology advancement effort) corresponding to Fig. 5 analysis.

Table 3 demonstrates that while SP elasticity to P_U maintains negative with smaller value in the 3rd period, learning co-efficient changed from negative to positive in the 2nd period and changed again to negative in the 3rd period. The former corresponds to the observation in Fig. 6 while the latter corresponds to the observation in Fig. 5.

Utilizing the results of Table 3, the contribution of Uber prices decrease can be identified as summarized in Table 4.

Looking at Table 4 we note that Uber's prices have been governed by the increase in its trips and own strategy together with the increase in smartphones. Contribution of trips increase can be attributed to learning and economy of scale effects (Watanabe et al., 2009 [32]) while contribution of smartphones increase can be attributed through ICT's self-propagating function that accelerates learning and economy of scale effects (Watanabe et al., 2004 [30], Watanabe et al., 2009 [32]).

As analyzed in Fig. 5, sharp decline in Uber prices stagnated from August 2004 and changed to upward trend by serious complaints about unexpectedly high charges due to surge pricing in October 2014. While this upward shifting factor remains, the price decline trend was maintained by introducing Uber Go in November 2014 together with technology advancement effort. This challenge in the 3rd period demonstrated high elasticity of trips to prices and compensated the stagnation of smartphones share increase in 2015. Upward trend in the 2nd period can be attributed to surge pricing strategy.

Table 4 demonstrates these rise and fall trends. Noteworthy is a resilient recovery in price decline in the 3rd period despite stagnation of smartphones contribution to this decline. This suggests a sophisticated dynamism in Uber's ICT-driven trips and prices coordination which is beyond simple ICT's self-propagating function as well as learning and economy of scale effect.

(2) Virtuous Cycle between Uber Trips Increase and Its Prices Decline

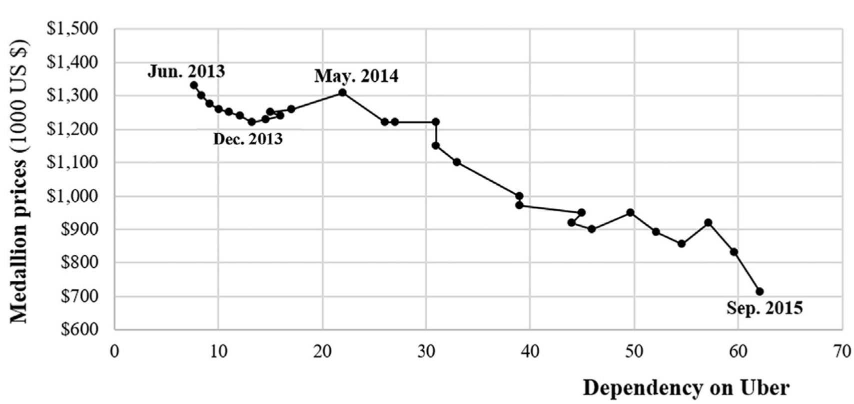


Fig. 9. Correlation between dependency on Uber and medallion prices in NYC (Jun. 2013.6 – Sep. 2015).
Sources: NYC Taxi and Limousine Commission (TLC) and Certify [6].

Inspired by the foregoing suggestion, Fig. 7 analyzes the correlation between Uber's trips and their prices in NYC over the same period.

Fig. 7 demonstrates three phases trends corresponding to the three periods in Table 4. While Uber's prices demonstrated sharp decline as smartphones increased in the 1st period, after recovering from the upward trend in the 2nd period, prices decline was maintained under trips increase initiative despite smartphones direct effect decreased. This dynamism prompts us the sources of Uber's success leading to its astounding rise as reviewed earlier. Given Uber as the jewel of ICT as reviewed in 2.1, this success is considered to depend on ICT's unique comprehensive function beyond simple self-propagation, learning and economy of scale effects.

4. Co-evolution of 3 mega-trends leading to a spinoff to sharing economy

4.1. Emergence of un-captured GDP

(1) Medallion Prices as a Proxy of the Trend in Taxi Demand

The medallion system (official taxi licenses with medallion, in place since 1937) sets an upper limit of the number of those cabs with licenses. As the demand grew, medallions became more and more valuable, resulting in higher medallions prices. Therefore, the trend in medallion prices can be considered as a proxy of a trend in taxi demand[3] and given its sustainable increase, Taxi medallions were considered the best investment in the US (Badger, 2014) [3].

Thus, this trend continuously increased, experiencing logistic growth as demonstrated in Table 5. This trend led to a sharp hike in medallion prices from 250 thousand US$ in January 2004 to a peak of 1.3 million US$ (for the corporate sector) in June 2013, as demonstrated in Fig. 8.

However, starting in May 2011, Uber added more and more drivers, the medallion prices started stagnating after a peak in June 2013. The prices then fell precipitously from May 2014, corresponding to the time when Uber prices reached the level of taxis prices as demonstrated in Fig. 5.

(2) Correlation between Dependency on Uber and Medallion Prices

The more cabs are booked through Uber, the less money the cab drivers make and the worse the taxi medallions look like as an investment. Medallion prices have continued to drop considerably after Uber, with prices declining, caught up with the price level of a traditional taxi in May 2014.

Fig. 9 illustrates the correlation between dependency on Uber (share of Uber trips out of sum of Uber and taxi trips) and medallion prices (as a proxy of taxi demand) in NYC over the period June 2013–September 2015.

Uber's astounding success brought its prices lower than a taxi in May 2014 (Fig. 5). Uber's success resulted in a significant decrease in medallion prices (Fig. 8). Reduced medallion prices (taxi demand decrease) induce further dependency on Uber, leading to a virtuous cycle between medallion prices decline and increase in this dependency, as demonstrated in Fig. 10.

This demonstrates a structural source of the contrast between precipitous fall of the medallion prices and astounding rise of Uber.

(3) Two-faced Nature of ICT and Subsequent Un-captured GDP

The impacts of Uber's sharing revolution on the medallion system in NYC can be classified into two periods:

(i) During the first two years after the launch of Uber in May 2011, Uber's share remained below 10% (Fig. 2), and its impact on medallion prices was limited. The medallion prices continued to increase, due primarily to the increase in demand for a taxi.
(ii) However, after this "pregnancy period," once Uber's share reached 10% in June 2013 overcoming the Chasm in a diffusion trajectory (Moore, 1999 [22]),[4] the sharing revolution made a structural change to the medallion price formation system, leading to the above-mentioned precipitous fall.

Table 5 suggests that without such sharing revolution which made a structural change in the price formation system, the medallion prices may continue to logistic growth as illustrated in Fig. 8 by a broken line. Contrast of actual and estimated medallion prices corresponds to the two-faced nature of ICT which postulates that while the advancement of ICT contributes to enhancing its prices by increasing new functionality development, dramatic advancement of the Internet tends to decrease ICT prices due to freebies, easy copying, and mass standardization, among other things as illustrated in Fig. 11 (Cowen, 2011 [10]).

This suggests the emergence of un-captured GDP as Uber advances. Advancement of ICT can largely be attributed to the dramatic advancement of the Internet, which has changed the computer-initiated ICT world significantly. The Internet promotes a free culture, consumption of which provides utility and happiness to people but cannot be captured through GDP data that measure revenue (Lowrey, 2011 [19]) leading to increasing dependency on un-captured GDP (Watanabe et al., 2014, 2015 [34,35]).

Uber's better service with cost and time savings for passengers by highly efficient operation without additional investment and license fees for drivers correspond to this concept. Therefore, discrepancy between actual medallion prices and estimated medallion prices without Uber in Fig. 8 can be considered as demonstrating the magnitude of un-captured GDP (See Appendix 2).

(4) Magnitude of the Emergence of Un-captured GDP

Inspired by the preceding observation with respect to emergence of un-captured GDP driven by the discrepancy induced by Uber, un-captured GDP emerged by Uber can be captured by measuring the discrepancy between taxi prices and magnitude of their decline effect derived from Uber as illustrated in Fig. 12. Since magnitude of taxi prices decline effect can be measured by the aggregated prices of taxi and Uber with respective trip share, un-captured GDP emerged by Uber can be measured by the following balance:

[3] Medallion prices demonstrate significant correlation with taxi trips as follows and support this view:

Correlation between Taxi Trips (T_T) and the Medallion Prices (MP) in NYC (monthly basis)

Jan. 2000 - May 2013 (Before *MP* stagnate due to Uber)

$$\ln MP = \underset{(-18.55)}{-9.573} + \underset{(30.56)}{4.174} \ln T_T \qquad adj.R^2\ 0.986 \quad DW\ 1.52$$

Jun. 2013 - Sep. 2015 (After *MP* stagnate)

$$\ln MP = \underset{(-3.78)}{-2.102} + \underset{(16.36)}{2.595} \ln T_T - \underset{(-3.87)}{1.147} D \qquad adj.R^2\ 0.911 \quad DW\ 1.04$$

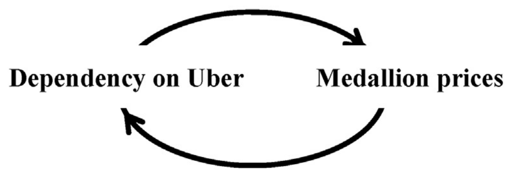
D: Dummy variables (Jun. 2013 and Sep. 2015 = 1, other months = 0).
Figures in parenthesis indicate t-value: all significant at the 1% level.

[4] Analysis based on the diffusion theory identifies this timing of Uber in NYC as early 2013 (See Appendix 2).

$$\ln MP_t = 8.435 - 0.554 D_1 \ln UD_{t-1} + 0.220 D_2 \ln UD_{t-1} - 0.420 D_3 \ln UD_{t-1} - 1.895 D_2 - 0.131 D \quad adj.\ R^2\ 0.948 \quad DW\ 1.77$$

(77.43) (−11.50) (1.06[*7]) (−14.22) (−3.31) (−5.07)

MP: Medallion prices, *UD*: Dependency on Uber, D_1, D_2, D_3, *D*: Dummy variables.
D_1: 2013.6 – 2013.12 = 1, rest = 0. D_2: 2014.1 – 2014.5 = 1, rest = 0. D_3: 2014.6 – 2015.9 = 1, rest = 0.
D: 2013.7-8, 2015.9 = 1, other months = 0.



$$\ln UD_t = 17.022 - 2.051 D_1 \ln MP_{t-1} + 11.030 D_2 \ln MP_{t-1} - 1.910 D_3 \ln MP_{t-1} - 92.770 D_2 \quad adj.\ R^2\ 0.980 \quad DW\ 1.46$$

(15.22) (−13.11) (3.06) (−11.88) (−3.62)

D_1: 2013.6 – 2013.12 = 1, rest = 0. D_2: 2014.1 – 2014.5 = 1, rest = 0. D_3: 2014.6 – 2015.9 = 1, rest = 0.

Fig. 10. Virtuous cycle between dependency on Uber and Medallion prices (Jun. 2013–Sep. 2015). Figures in parenthesis indicate t-statistics: all significant at the 1% level except [*7]: 30% level.

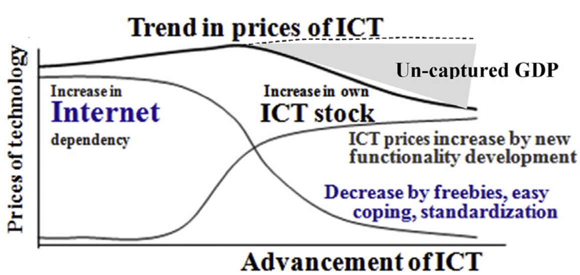


Fig. 11. Two-faced nature of ICT.

$$\text{Un} - \text{captured GDP} = P_T - P_A = P_T - \frac{T_T \cdot P_T + U_T \cdot P_U}{T_T + U_T} = P_T - \frac{P_T + \alpha \cdot P_U}{1+\alpha} = \frac{1}{1+\frac{1}{\alpha}}(P_T - P_U)$$

where *PT*: Taxi prices, *PU*: Uber prices, *PA*: Aggregated prices, *TT*: Taxi trip, *UT*: Uber trip, α: *UT*/*TT* ratio.

Fig. 12 demonstrates the significant parallel correlation between taxi prices (P_T) and estimated medallion prices without Uber (*Mpe*), as well as aggregated prices (P_A) and actual medallion prices (*MP*) (See Appendix 3). This endorses the view that the balance between

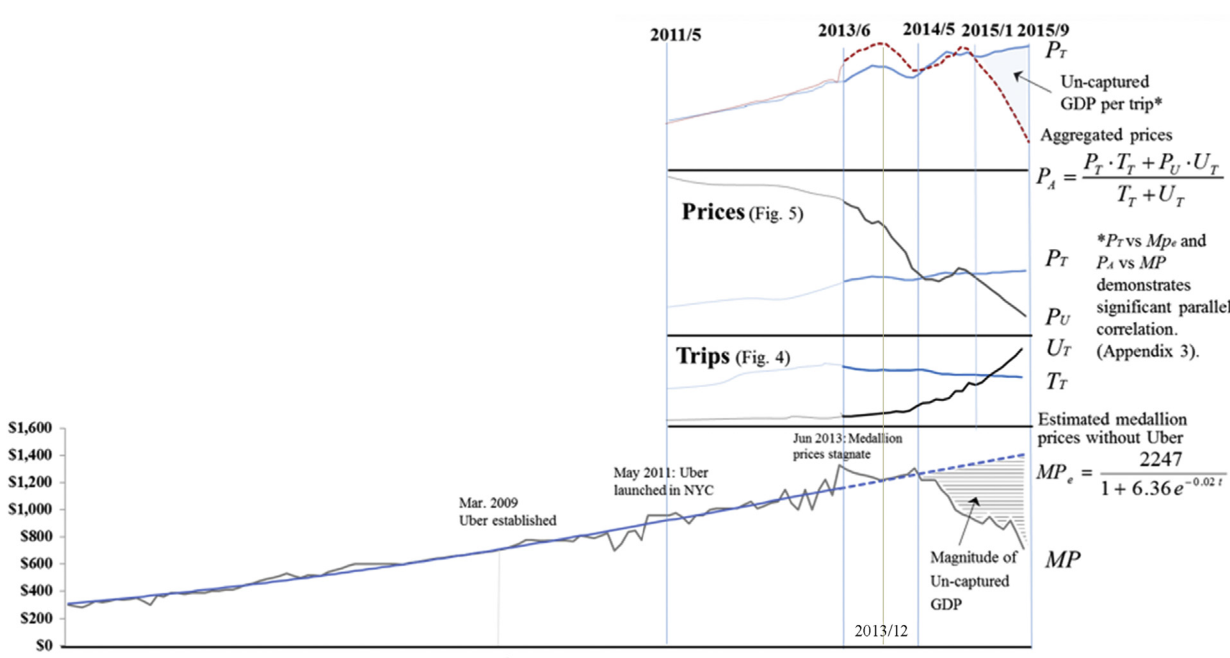


Fig. 12. Scheme of the measurement of the emergence of un-captured GDP emerged by Uber in NYC.

taxi prices and aggregated prices represents the emergence of un-captured GDP emerged by Uber.

4.2. Emergence of Uber-driven un-captured GDP

(1) Substance of the Uber-driven Un-captured GDP

Supported by the preceding endorsement, Fig. 13 demonstrates the magnitude of un-captured GDP per trip emerged by Uber.

Aggregated prices P_A are measured by the following equation: $P_A = \frac{P_T \cdot T_T + P_U \cdot U_T}{T_T + U_T}$

The substance of this un-captured GDP can be summed up as follows:

High-qualified services with lower cost and shorter time. An increasing initiative of passengers and the company's systematic market strategy of continuous reduction of costs and time in search and matching, eliminating information asymmetries and compiling a massive database.

Fig. 13 demonstrates that while Uber nurtured "negative un-captured GDP value" (its services were unable to catch up with those of taxi accumulated over the last 120 years) by June 2014, it succeeded in nurturing increasing un-captured GDP from the beginning of 2015 corresponding to its success in sustainable decline in prices from the end of 2014 (Fig. 5).

(2) Increase in the Emergence of Un-captured GDP

On the basis of the preceding review, the trend in the value of un-captured GDP per trip by Uber in NYC was measured as illustrated in Fig. 14. This Figure demonstrates that un-captured GDP induced by Uber has been increasing significantly from the beginning of 2015.

As emulating in the following equation, this can be attributed to a virtuous cycle between Uber's prices (P_U) decline and trips (U_T) increase.

$$\text{Un-captured GDP} = P_T - P_A = P_T - \frac{T_T \cdot P_T + U_T \cdot P_U}{T_T + U_T} = P_T - \frac{P_T + \alpha \cdot P_U}{1+\alpha} = \frac{1}{1+\frac{1}{\alpha}}(P_T - P_U)$$

where $\alpha = \frac{U_T}{T_T}$ ratio

4.3. Spinoff to sharing economy

(1) New Functionality Development During Diffusion Process

Uber's conspicuous virtuous cycle between prices decline, and increased trips can largely be attributed to its self-propagating function incorporating new functionality development during its diffusion process as was prompted by the analysis in Fig. 7.

Diffusion trajectory of innovative goods Y (trips of taxis and Uber in this case) can be depicted by the following epidemic function:

$$\frac{dY(t)}{dt} = aY(t)\left(1 - \frac{Y(t)}{N}\right) \quad (1)$$

where N: carrying capacity (sealing the adoption of innovative goods) and a: coefficients governing diffusion velocity.

This equation leads to the following simple logistic growth (SLG) function:

$$Y(t) = \frac{N}{1 + be^{-at}} \quad (2)$$

where b: coefficient indicating initial state of the diffusion.

While the level of carrying capacity is assumed constant through the diffusion process in this function, in particular innovations, the correlation of the interaction between innovation and institutions displays a systematic change in the process of growth and maturity. This leads to the creation of a new carrying capacity in the process of its diffusion similar to equation (1) as follows:

$$\frac{dY(t)}{dt} = aY(t)\left(1 - \frac{Y(t)}{N(t)}\right) \quad (3)$$

This equation leads to the following logistic growth within a dynamic carrying capacity (LGDCC) function, which demonstrates the level of carrying capacity enhancement as the diffusion proceeds (Meyer et al., 1999 [21]):

$$Y = \frac{N_k}{1 + be^{-at} + \frac{b_k}{1 - a_k/a} e^{-a_k t}} \quad (4)$$

where Nk: ultimate carrying capacity, and ak and bk: coefficients similar to a and b.

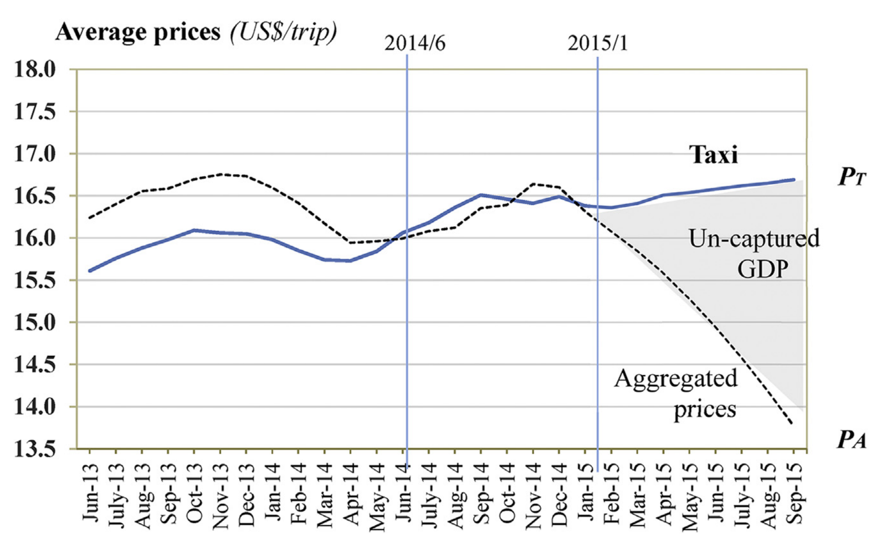


Fig. 13. Trends in taxi prices and aggregated prices in NYC (*Jun. 2013 – Sep. 2015*).

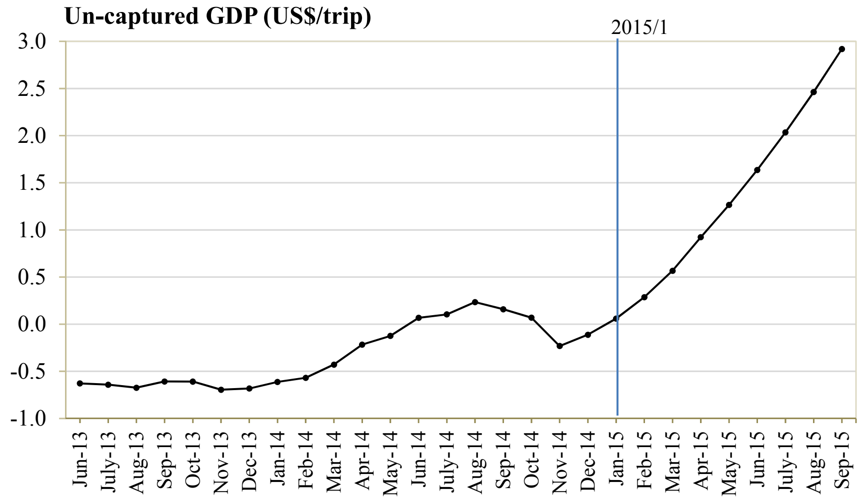


Fig. 14. Trend in the emergence of un-captured GDP emerged by Uber in NYC (*Jun. 2013 – Sep. 2015*).

Equation (4) demonstrates that the 3rd term of the denomination governs the dynamic carrying capacity and without this term results in SLG with a constant carrying capacity.

(2) Uber's Self-propagating Function

From equation (3), dynamic carrying capacity can be expressed as follows:

$$N(t) = Y(t)\left(\frac{1}{1 - \frac{1}{a}\cdot\frac{dY(t)}{dt}\Big/Y(t)}\right) \tag{5}$$

This demonstrates that *N(t)* increases together with the increase of *Y(t)*, and its growth rate as time goes by. This implies that the LGDCC function demonstrates functionality development in the context of the self-propagating behavior (Watanabe et al. (2004) [30], Watanabe et al. (2009) [32]).

Table 6 compares this self-propagating function in taxi and Uber in NYC by examining their adaptability to LGDCC.

Table 6 demonstrates that while taxis depend on SLG as its 3rd term of the denomination (a_k and b_k) demonstrates statistically insignificant, Uber demonstrates depending on LGDCC with statistically significant 3rd term of the denomination.

This demonstrate that Uber has developed with the self-propagating function.

(3) Spinoff from Taxi to Uber

This self-propagating function plays a vital role of the engine in spinning-off from traditional co-evolutional three mega-trends to new co-evolution as illustrated in Fig. 15. This spin-off plays significant role in inducing ICT-driven innovation (Watanabe et al. (2015, 2016) [35,36]). Here spin-off is defined as jumping to more sophisticated co-evolutional dynamism from traditional co-evolutional dynamism in inducing innovation (Watanabe et al., 2011 [33]).

From equation (5) functionality development in the LGDCC function can be depicted as follows:

$$\text{Functionality development} = FD = \frac{N(t)}{Y(t)} = \frac{1}{1 - \frac{1}{a}\cdot\frac{dY(t)}{dt}\Big/Y(t)} \tag{6}$$

This equation demonstrates that functionality development can be accelerated as its growth rate increases. Since functionality development plays a locomotive role in leveraging spin-off (Watanabe et al. (2011) [33]), equation (6) indicates self-propagating function leverages spin-off by inducing functionality development.

This spin-off can be observed in industries not only transportation (Fig. 16) but also music industry, game industry and printing and publishing industry. Nowadays, even education industry has been behaving the similar trend.

4.4. Dynamism of Uber's ICT driven disruptive business model

By the preceding analyses, the dynamism of Uber's ICT driven disruptive business model can be identified as illustrated in Fig. 17.

Co-existing development trajectory with taxi corresponds to two-faced nature of ICT that is behind the emergence of un-captured GDP.

This emergence can be attributed to a strong substitution from taxi to Uber accelerated by contrasting vicious cycle between price increase and trips decrease in taxi and a virtuous cycle between price decline and trips increase in Uber.

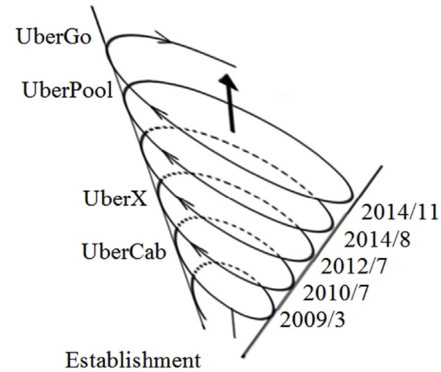
Uber's virtuous cycle can be attributed to ICT's self-propagating function that enhances the level of functionality as its diffusion proceeds.

This self-propagating function plays a vital role in spin-offs from traditional co-evolution to new co-evolution between ICT advancement, paradigm change to increasing un-captured GDP

Table 6
Adaptability of taxi and Uber's development trajectories to LGDCC (NYC).

	N_k	a	b	a_k	b_k	adj. R^2
Taxi (Jan. 2004 –Jun.2013)	2247.12 (6.42)	0.017 (12.61)	6.364 (6.63)	0.439 (0.00^{x})	10.30 (0.00^{x})	0.976
Uber (Jun.2013 –Sep.2015)	119.27 (41.41)	0.121 (36.67)	49.650 (11.13)	0.016 (2.42^{*3})	0.200 (1.43^{*5})	0.999

Taxi: based on medallion prices (Fig. 8), Uber: based on trips (Fig. 4) with spline interpolation (see Appendix 4).
LGDCC: Logistic growth with dynamic carrying capacity, $Y = \frac{N_k}{1+be^{-at}+\frac{b_k}{1-a_k/a}e^{-a_k t}}$ (eq. (4)).
Figures in parenthesis indicate t-statistics: all significant at the 1% level except ^{*3}: 5%, ^{*5}: 15%, ^{x}: non-significant.



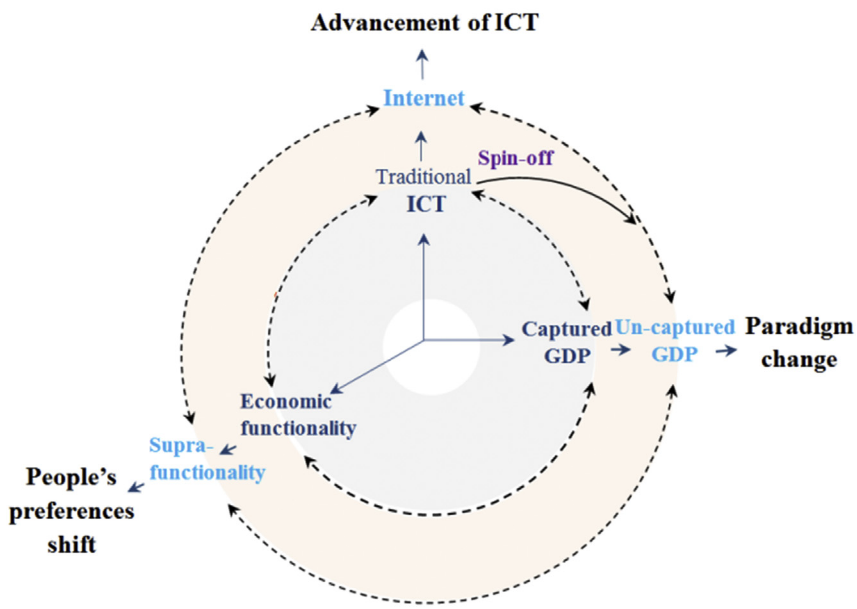


Fig. 15. Scheme of spin-off dynamism.

dependence, and people's preferences shift to supra-functionality beyond economic value.

This spin-off accelerates further lower cost and higher services, which accelerates the foregoing virtuous cycle.

Uber's success can be attributed to constructing such ICT driven disruptive business model.

Business models have been moving from pipes to platforms and we are in the midst of transformative shift in business design. Platforms allow participants to co-create and exchange value with each other. External developers can extend platform functionality and contribute back to the infrastructure of the business. Platform users who act as producers can create value on the platform for other users to consume. All have been demonstrated by Uber.

Uber's disruptive business model can be thus appreciated as a leader of transformative shift in business design by constructing the foregoing platform ecosystem.

5. Conclusion

5.1. Secret of the Uber's system success

In light of the disruptive digital-technology-driven business model that Uber has used to trigger a ride-sharing revolution, the institutional sources of the company's platform ecosystem architecture were analyzed.

Aiming at elucidating institutional enablers creating Uber's platform ecosystem, an empirical analysis of its co-existing development trajectory with taxi was attempted.

Noteworthy findings include:

(i) This co-existing development trajectory corresponds to two-faced nature of ICT that is behind the emergence of un-captured GDP,

(ii) This emergence can be attributed to a strong substitution from taxi to Uber accelerated by contrasting vicious cycle between price increase and trips decrease in taxi and a virtuous cycle between price decline and trips increase in Uber,

(iii) Uber's virtuous cycle can be attributed to ICT's self-propagating function that enhances the level of functionality as its diffusion proceeds,

(iv) This self-propagating function plays a vital role in spin-offs from traditional co-evolution to new co-evolution between ICT advancement, paradigm change to increasing un-captured GDP dependence, and people's preferences shift to supra-functionality beyond economic value,

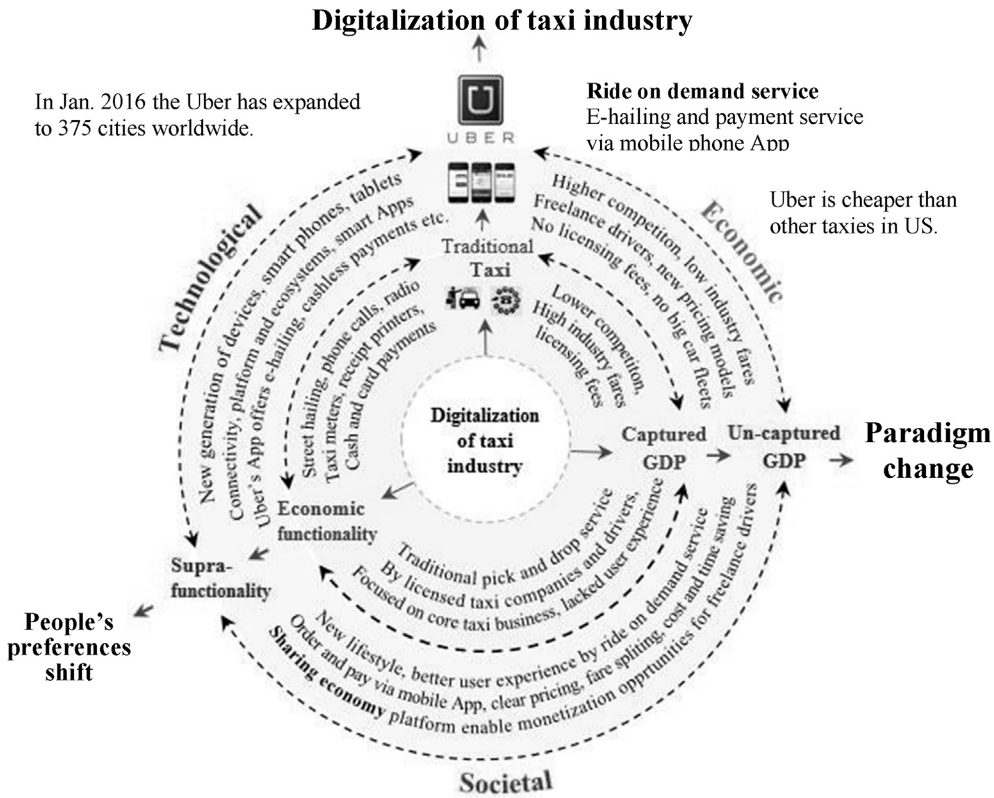


Fig. 16. Co-evolution of 3 mega-trends in transportation industry.

(v) This spin-off accelerates further lower cost and higher services, which accelerates the foregoing virtuous cycle, and
(vi) Uber's success can be attributed to constructing such ICT driven disruptive business model.

5.2. *Noteworthy elements essential to well-functioning platform ecosystem architecture*

These findings form the base for the following suggestions supportive to constructing a well-functioning platform ecosystems:

(i) Penetrate the current demand and challenge to meet it (e.g., sharing economy, saturation of taxi business, popularity of smartphone),
(ii) Fully utilize the advancement of ICT, particularly of the Internet (e.g., smartphone, digital payment, big data analysis),
(iii) Construct a co-evolution between sophisticated platform ecosystems and consolidation of broad stakeholders (e.g., mutual rating system among company, its drivers, and their passengers),
(iv) Take care of the platform orchestration for efficiency, development and innovation (e.g., successive innovation for novel services as competitor like Lyft boosting and also as against movement emerging),
(v) Thereby, creating a novel business model which has never been conceived before.

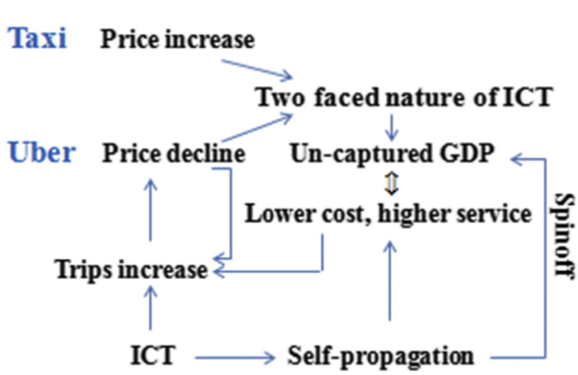


Fig. 17. The dynamism of Uber's ICT driven disruptive business model.

5.3. *Implications of un-captured GDP*

The emergence of un-captured GDP emerged by Uber can be attributed to:

(i) People's preferences shift to sharing economy and advancement of ICT, particularly of the Internet and subsequent smartphones,
(ii) Better services, with cost and time saving for passengers, high efficient operation without additional investment and licenses fees for drivers, and optimal price-setting and market making beyond marginal cost for company through a massive database on driver and passenger behavior, and
(iii) The paradigm shift from resources to the ecosystem that corresponds to the shift from captured GDP to un-captured GDP.

Thus, Uber's un-captured GDP can be considered as a consequence of the co-evolution between people's preferences shift, advancement of ICT and this paradigm shift.

This co-evolution has been leveraged Uber to create new business, to create services through interactions between stakeholders: company, drivers, and passengers.

All this can be attributed to systems success: platform ecosystem architecture under the contemporary digital economy.

5.4. Criticism to be solved

However, as a consequence of the transition to this new dynamism, there remain the following areas of criticism:

(i) Business philosophy for discrimination (e.g., equivalence of services for remote areas with low population density),
(ii) Safety issues,
(iii) Treatment of privacy issues, and
(iv) Compliance with labor standards.

Given the noted contrast between co-evolutionary success with institutional systems in host countries/cities and legal battles with quite a few countries/cities through Uber's global expansion, the sources of this contention as a a consequence of business strategy, platform ecosystems design, and institutional systems in host country/city should be further studied.

5.5. Future works

This analysis has explored a prototype of the analysis of the ICT-driven disruptive business model using the analysis of the co-evolution of three mega-trends that nurtures un-captured GDP.

Furthermore, analyses applying this approach is expected to be undertaken for similar disruptive business models in the (i) music industry, (ii) electronic gaming industry, (iii) printing and publishing industry, and (iv) education. In addition, business areas as fintech, legal and real estate should also be explored.

Acknowledgement

The research leading to these results has received funding from the Strategic Research Council at the Academy of Finland under grant agreement no: 293446 – Platform Value Now: Value capturing in the fast emerging platform ecosystems.

Appendix 1. Data construction

As a consequence of the numerical analysis of newly emerged innovation, elucidation of Uber's systems success was a challenge in exploring the dark continent without published statistical data. Therefore, the challenge started from constructing series of reliable statistical data which can be summarized as follows. A sensitive analysis of the estimated data was conducted to ensure the reliability of constructed data, (Appendix 4).

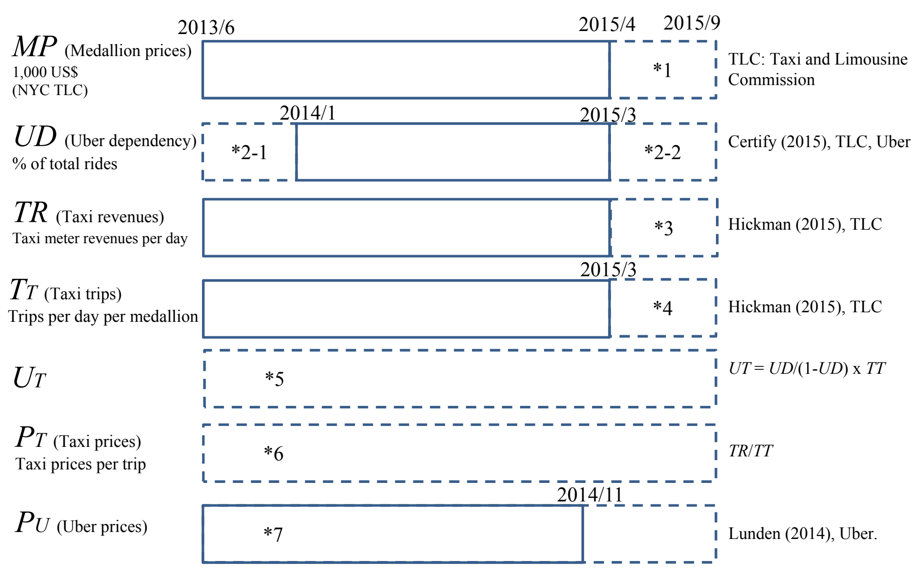


Fig. A1. Estimate of Supplemental Period *(2013/6 – 2015/9).*

*1 : Estimated parallel with individual's medallion prices

*2-1: $UD = Ae^{\lambda t}$

*2-2: $UD = a + bt + ct^2$

*3 : $TR = Ae^{\lambda t}$

*4 : $T_T = Ae^{\lambda t}$

*5 : $U_T = \frac{UD}{1-UD} \times T_T \quad U_T = \frac{N}{1+be^{-at}}$

*6 : $P_T = \frac{TR}{T_T}$

*7 : $PU = a + bt + ct^2$

Data were constructed by cross evaluating earlier work listed on the right-hand side and data/information by TLC and Uber. Supplemental estimate of the missing periods of the above estimates was based primarily on the spline functions illustrated above.

Appendix 2. Two-faced nature of ICT and un-captured GDP

A2.1 Two-faced nature of ICT and subsequent un-captured GDP

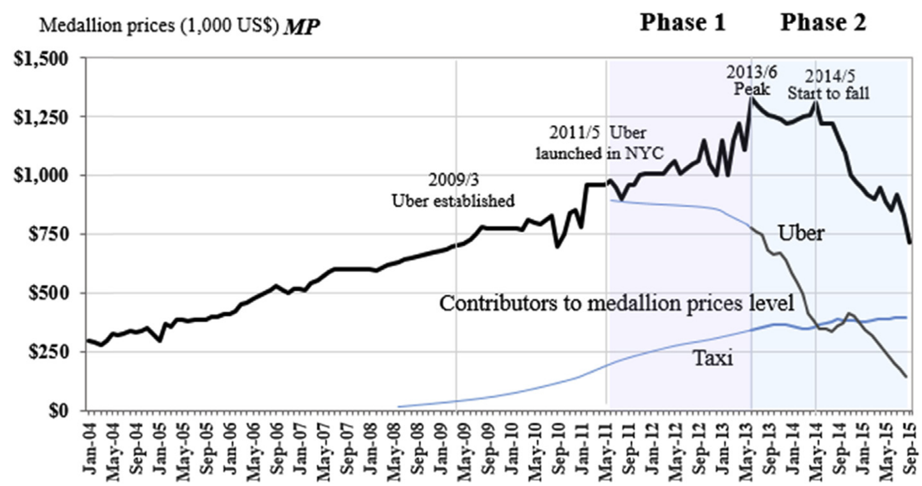


Fig. A2. Trend in Corporate Medallion Prices in NYC and Contributors *(2004–2015)*.
Source: NYC Taxi and Limousine Commission.

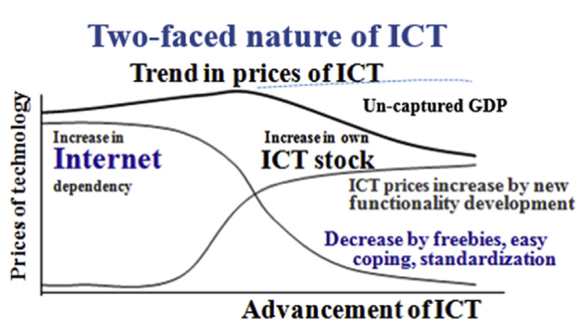


Fig. A3. Two-faced Nature of ICT.

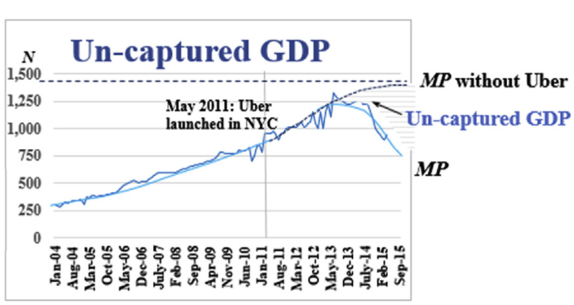


Fig. A4. Anticipating Un-captured GDP.

The trend in medallion prices as a consequence of co-existing diffusion trajectory of a taxi with prices increase and that of Uber with prices decrease suggests that this trajectory is subject to the two-faced nature of ICT that is behind the emergence of un-captured GDP.

A2.2 ICT prices trajectory and two-faced nature

(1) Modified Bi-logistic Growth

ICT prices can be depicted by the following modified bi-logistic growth as illustrated in Fig. A5:

$$p_I = \frac{N}{1 + b_j e^{-a_j J}} + \frac{N}{1 + b_i e^{a_i I}} \tag{A1}$$

where I: ICT stock, J: dependency on the Internet, N: carrying capacity, a_i, a_j *and* b_i, b_j: diffusion velocity of I and J.[5]

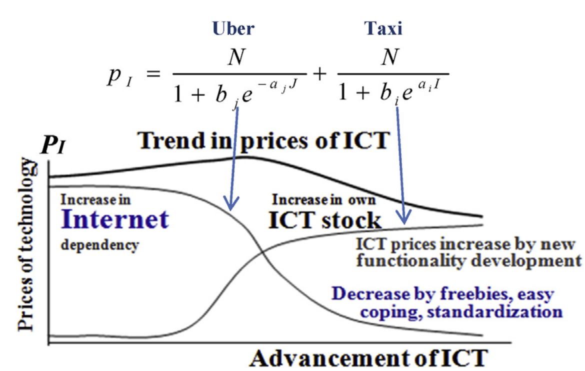


Fig. A5. Modified Bi-logistic Growth due to Two-faced Nature of ICT.

Equation (A1) can be developed as follows:

[5] Since the Internet has been playing a leading role in the whole ICT and providing significant impacts on the diffusion trajectory of ICT, carrying capacity of logistic growth in I and reverse logistic growth in J as well as their diffusion tempo ($a_i I$ *and* $a_j J$) were treated as behaved in the similar way ($a_i I = a_j J$).

When $I = 0$, $p_I = \varepsilon(\approx 0), \frac{N}{1+b_i} = \varepsilon, b_i = \frac{N}{\varepsilon} - 1$. *When* $I = \infty, p_I = N$.

When $J = 0, p_J = N - \varepsilon, \frac{N}{1+b_j} = N - \varepsilon, b_j = \frac{\varepsilon}{N-\varepsilon}$. *When* $J = \infty, p_I = 0$.

Therefore, $b_i >> b_j$.

$$\frac{p_I}{N}=\frac{1+b_je^{a_jJ}+1+b_ie^{-a_iI}}{\left(1+b_ie^{-a_iI}\right)\left(1+b_je^{a_jJ}\right)}=\frac{2+b_je^{a_jJ}+b_ie^{-a_iI}}{1+b_je^{a_jJ}+b_ie^{-a_iI}+b_ib_je^{-a_iI}e^{a_jJ}}$$
$$\approx\frac{2+b_je^{a_jJ}+b_ie^{-a_iI}}{1+b_ib_j+b_je^{a_jJ}+b_ie^{-a_iI}}=1+\frac{1-b_ib_j}{1+b_ib_j+b_je^{a_jJ}+b_ie^{-a_iI}}$$
$$\frac{p_I}{N}-1=\frac{1-b_ib_j}{1+b_ib_j+b_je^{a_jJ}+b_ie^{-a_iI}}$$
$$\frac{N}{N-p_I}=\frac{1}{1-\frac{p_I}{N}}=-\frac{1+b_ib_j}{1-b_ib_j}-\frac{b_je^{a_jJ}}{1-b_ib_j}-\frac{b_ie^{-a_iI}}{1-b_ib_j}$$
$$\approx-\frac{1+b_ib_j}{1-b_ib_j}-\frac{b_j}{1-b_ib_j}(1+a_jJ)-\frac{b_i}{1-b_ib_j}(1-a_iI)$$
$$=\frac{1+b_ib_j+b_i+b_j}{b_ib_j-1}+\frac{a_jb_j}{b_ib_j-1}J-\frac{a_ib_i}{b_ib_j-1}I\equiv\alpha+\beta J+\gamma I \quad (A2)$$

$$\text{where}\quad \alpha=\frac{1+b_ib_j+b_i+b_j}{b_ib_j-1}=\frac{(1+b_i)(1+b_j)}{b_ib_j-1}<0,\quad \beta=-\frac{a_jb_j}{b_ib_j-1}<0,\quad \gamma=-\frac{a_ib_i}{b_ib_j-1}>0 \quad (A3)$$

In case of a co-existing diffusion of taxis and Uber, J and I correspond to UT (Uber trips) and TT (taxi trips) and Eq. (A2) can be represented as Table A1.

Table A1
Co-existing Trajectory of Taxis and Uber in NYC (*Jun. 2313 − Sep. 2015*).

$$\frac{N}{N-MP}=\underset{(-3.12)}{-1.355}-\underset{(-2.96)}{0.005}U_T+\underset{(8.54)}{0.103}T_T+\underset{(5.42)}{0.178}D \qquad adj.R^2\ 0.970\quad DW\ 1.35$$

Where N (carrying capacity) = 2247, (Table 5) MP: medallion prices, D: 2014. May, Aug., Sep. = 1.

Figures in parenthesis indicate t-statistics: all significant at the 1% level.

Figures in parenthesis indicate t-statistics: all significant at the 1% level.

This demonstrates that coexistence of taxi and Uber is subject to two-faced nature of ICT.

(2) Diffusion Coefficient

Coefficients governing modified bi-logistic growth in Eq. (A1) can be identified as follows (here J and I correspond to UT and TT):

$$\frac{\beta}{\gamma}=-\frac{a_jb_j}{a_ib_i}=-\frac{I}{J}\cdot\frac{b_j}{b_i}\left(\because a_iI=a_jJ\right)\quad Therefore,$$
$$b_j=-\frac{\beta}{\gamma}\cdot\frac{J}{I}\cdot b_i\equiv\eta b_i\left(\eta=-\frac{\beta}{\gamma}\cdot\frac{J}{I}<<1\ as\ b_j<<b_i\right)$$
$$\alpha=-\frac{1+\eta b_i^2+(1+\eta)b_i}{1-\eta b_i^2}\ (\alpha-1)\eta b_i^2-(1+\eta)b_i-(\alpha+1)=0$$

$$b_i=\frac{(1+\eta)-\sqrt{(1+\eta)^2+4(\alpha-1)(\alpha+1)\eta}}{2(\alpha-1)\eta}(>0)$$
$$b_j=\eta b_i=\frac{(1+\eta)-\sqrt{(1+\eta)^2+4(\alpha-1)(\alpha+1)\eta}}{2(\alpha-1)}(>0) \quad (A4)$$
$$as\ \alpha<0.\quad \alpha<-1\ is\ necessary\ for\ b_i,b_j>0.$$

$$a_i=\gamma\cdot\frac{1-b_ib_j}{b_i}=\gamma\left(\frac{1}{b_i}-b_j\right)(>0)\quad a_j$$
$$=-\beta\left(\frac{1}{b_j}-b_i\right)(>0)\quad b_ib_j<1,b_i<\sqrt{\frac{1}{\eta}},b_j<\sqrt{\eta} \quad (A5)$$

Thus, co-existing trajectory of taxis and Uber as demonstrated in Table A1 can be demonstrated as follows:

$$P_I=\frac{2247}{1+0.03e^{0.20U_T}}+\frac{2247}{1+0.31e^{-0.33T_T}} \quad (A6*)$$

* Demonstrate the state in Sep. 2015 when $\eta=0.08$.

This modified bi-logistic growth demonstrates contributors to medallion prices level illustrated in Fig. A2.

(3) Trip Elasticity to Prices

The marginal contribution of Uber and taxis dependency to medallion prices change can be depicted as follows:

$$p_I=\frac{N}{1+b_je^{a_jJ}}\Rightarrow\frac{\partial p_I}{\partial J}=-a_jp_I\left(1-\frac{p_I}{N}\right),p_I=\frac{N}{1+b_ie^{-a_iI}}\Rightarrow\frac{\partial p_I}{\partial I}=a_ip_I\left(1-\frac{p_I}{N}\right) \quad (A7)$$

Thus, the elasticity of Uber and taxi dependency to prices elasticity can be depicted as follows:

$$\kappa_j\equiv\frac{\partial p_J}{\partial J}\cdot\frac{J}{p_J}=-a_jJ\left(1-\frac{p_J}{N}\right)=-\frac{a_jJ}{\alpha+\beta J+\gamma I}<0$$
$$\kappa_i\equiv\frac{\partial p_I}{\partial I}\cdot\frac{I}{p_I}=a_iI\left(1-\frac{p_I}{N}\right)=\frac{a_iI}{\alpha+\beta J+\gamma I}>0 \quad (A8)$$

This demonstrates that contrary to taxis prices increase as their trips increase, Uber prices decrease as its trips increase leading a virtuous cycle for Uber. All this support the analysis of institutional sources being behind the emergence of un-captured GDP.

A2.3 Prospect of un-captured GDP nurtured by Uber

As reviewed in Fig. 8, the magnitude of un-captured GDP can be measured by the balance between actual medallion prices and medallion prices without Uber.

While the former can be estimated by Eq. (A6), the latter can be estimated by Table A2. Table A2 demonstrates how the trend in medallion prices without Uber can be estimated both by logistic growth and parabolic growth. The latter provides a higher estimate.

Fig. A7 demonstrates prospect of un-captured GDP emerged by Uber estimated by the preceding approach.

A2.4 Timing when Uber overcame chasm

Chasm is a deep trench compelling new ventures start-up (Moore, 1991) [22].

It's timing in the logistic growth diffusion trajectory can be depicted as follows (Watanabe et al., 2011) [33]:

$$t = \frac{\ln\left(2-\sqrt{3}\right)b}{a} \quad \text{(A9)}$$

where logistic growth diffusion trajectory is: $Y = \frac{N}{1+be^{-at}}$

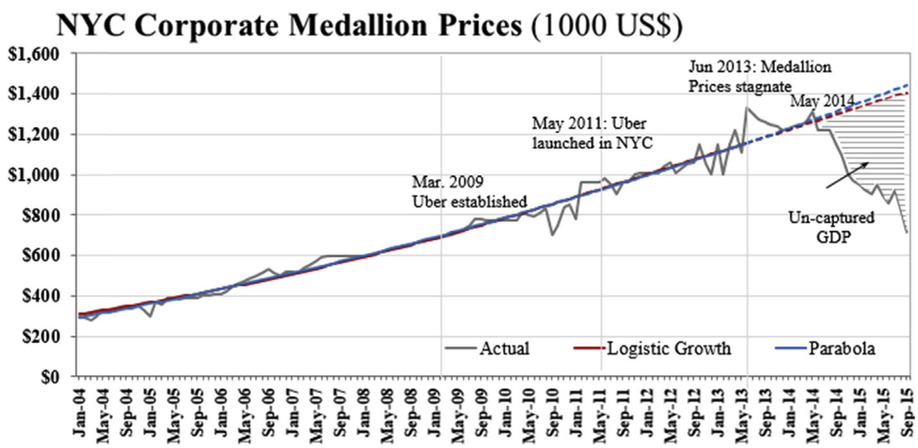


Fig. A6. Estimate of Uber's Impact on Medallion Prices Decline (Jan. 2004–Sep. 2015).

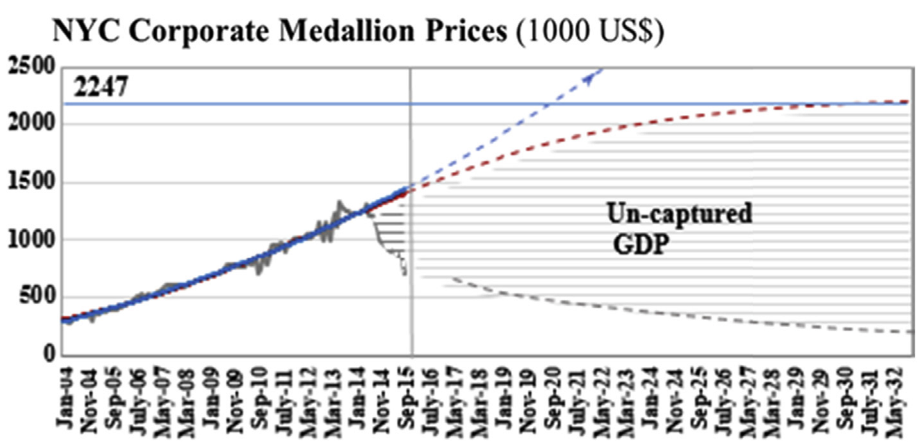


Fig. A7. Estimate of Un-captured GDP Anticipated by Uber *(May. 2014 – May. 2032)*.

Table A2
Estimates of Medallion Prices *(Jan. 2004 – Jun. 2013)*.

Logistic growth $Y = \frac{N}{1+be^{-at}}$				Parabolic growth $Y = a + bt + ct^2$			
	Estimate	*t-value*	*adj. R^2*		*Estimate*	*t-value*	*adj. R^2*
N	2247.11	7.23	0.976	*a*	288.30	25.80	0.977
a	0.02	14.21		*b*	5.31	11.91	
b	6.36	7.21		*c*	0.02	5.42	

Y: Medallion prices, *N*: Carrying capacity, *t*: Monthly trend, *a*, *b*, *c*: Coefficients.

In case of the following logistic growth within a dynamic carrying capacity (LGDCC) diffusion trajectory, a and b in the above equation can be approximated as follows (Watanabe et al., 2009) [31]:

$$t = \frac{\ln\left(2-\sqrt{3}\right)b'}{a'}, a' = a\left(1-\frac{b_k}{b}\right), b' = b\cdot\exp\left(\frac{b_k}{b}\cdot\frac{1}{1-\frac{a_k}{a}}\right) \quad \text{(A10)}$$

$$Y = \frac{N_k}{1+be^{-at}+\frac{b_k}{1-a_k/ae^{-a_k t}}}$$

Provided that Uber has been developing in line with the LGDCC diffusion trajectory as demonstrated in Table 6 in NYC from its launching in May 2011 ($t = 1$), t in eq (A10) can be $t = 21.5$ (March 2013).

This demonstrates that Uber has overcome the Chasm at the timing just before its share reached 10% in June 2013.

Appendix 3. Correlation between Medallion prices and taxi/Uber prices

Fig. A8 illustrates the correlation between taxi/Uber aggregated prices (*PA*) and medallion prices (*MP*) over the period May 2014–September 2015.

Similarly, Fig. A9 illustrates the correlation between taxi prices (P_T) and medallion prices without Uber (*MPe*) over the period May 2014–September 2015.

PT vs. *MPe* and *PA* vs. *MP* demonstrates significant parallel correlation as far as 2015 is concerned and supports the significance of un-captured GDP measurement depending on the balance between *PT* and *PA* during the above period.

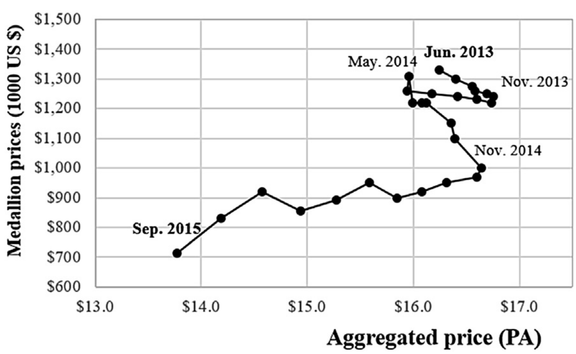


Fig. A8. Correlation between Taxi/Uber Aggregated Prices (*PA*) and Medallion Prices (*MP*) *(2014.5– 2015.9).*

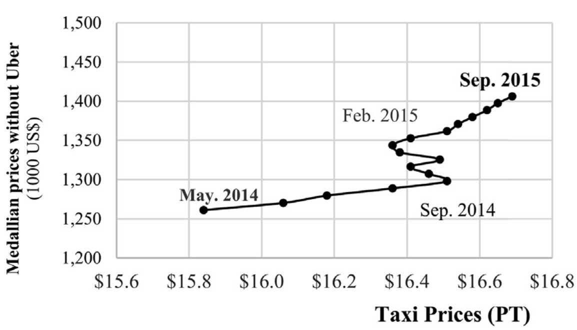


Fig. A9. Correlation between Taxi Prices (P_T) and Medallion Prices without Uber (*MPe*) *(2014.5 – 2015.9).*

Table A3
Correlation between Taxi/Uber Prices and Medallion Prices *(2014.5 – 2015.9).*

$$\ln MP = 3.3441 - 5.607 D_1 \ln P_A + 1.227 D_2 \ln P_A + 19.247 D_1 \quad adj.\ R^2\ 0.931 \quad DW\ 1.73$$

(5.38) (−4.81) (5.24) (5.81)

MP: Medallion prices, P_A: Aggregated prices per trip and D_1, D_2: Dummy variables.
D_1: 2014.5 – 2014.11 = 1, rest = 0, D_2: 2014.12 – 2015.9 = 1, rest = 0.

$$\ln MP_e = 4.018 + 1.127 D_1 \ln P_T - 2.731 D_2 \ln P_T + 1.144 D_3 \ln P_T + 10.813 D_2 \quad adj.\ R^2\ 0.945 \quad DW\ 1.26$$

(4.88) (3.80) (−2.84) (3.90) (3.84)

MPe: Estimated Medallion prices, P_T: Taxi prices per trip and D_1, D_2, D_3: Dummy variables.
D_1: 2014.5– 2014.8 = 1, rest = 0, D_2: 2014.9– 2015.1 = 1, rest = 0, D_3: 2015.2– 2015.9 = 1, rest = 0.

Figures in parenthesis indicate t-statistics: all significant at the 1% level.

Appendix 4. Sensitivity of Uber trips estimate

A4.1 Estimate without and with Spline interpolation

In analyzing Uber diffusion trajectory (4.3 (1) and (2)), given the sensitive impacts of fluctuation on the trajectory formation within the limited samples, a comparative analysis was attempted by comparing Uber trips estimate with and without spline interpolation as shown in Fig. A10 and Table A4. The function used for the spline interpolation was based on the logistic growth function (Appendix 1).

Table A4
Comparison of Uber trips estimate (Jun. 2013–Sep. 2015).

Period	Trips per day	
	U_T	U_{T2}
1 Jun-13	3.12	2.75
2 July-13	3.37	3.09
3 Aug-13	3.62	3.47
4 Sep-13	3.96	3.9
5 Oct-13	4.34	4.38
6 Nov-13	4.82	4.92
7 Dec-13	5.38	5.51
8 Jan-14	5.96	6.18
9 Feb-14	6.65	6.92
10 Mar-14	6.18	7.74
11 Apr-14	7.19	8.66
12 May-14	9.96	9.67
13 Jun-14	12.40	10.79
14 July-14	12.80	12.03
15 Aug-14	14.92	13.39
16 Sep-14	14.56	14.89
17 Oct-14	15.86	16.52
18 Nov-14	20.46	18.31
19 Dec-14	20.40	20.25
20 Jan-15	26.18	22.25
21 Feb-15	25.06	24.62
22 Mar-15	26.83	27.05
23 Apr-15	30.96	29.66
24 May-15	33.95	32.43
25 Jun-15	37.27	35.36
26 July-15	40.94	38.44
27 Aug-15	45.03	41.67
28 Sep-15	49.64	45.03

UT: Uber trips estimated by taxis trips and Uber dependency (Appendix 1).
UT2: Uber trips estimate with spline interpolation.

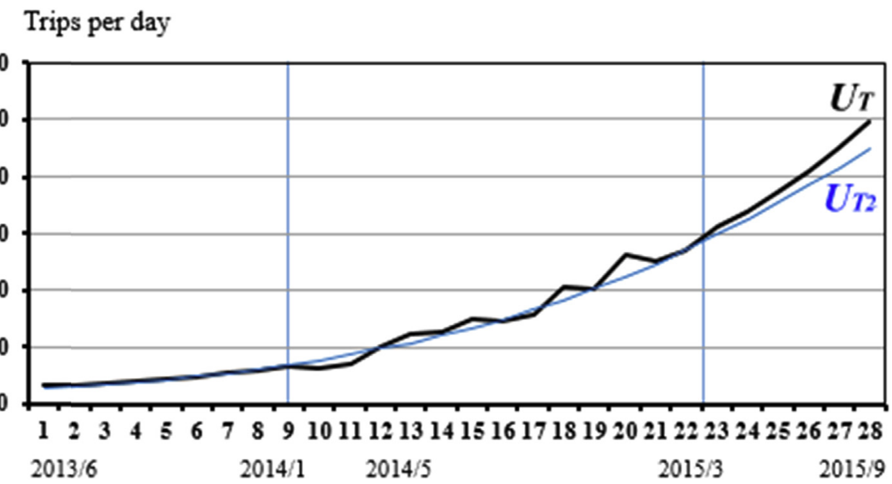


Fig. A10. Comparison of Uber Trips Estimate *(Jun. 2013 – Sep. 2015)*.

A4.2 Effects of the estimates of Uber-driven un-captured GDP

(1) Un-captured GDP emerged by Uber

Sensitivity analysis of the effects of the estimated data was conducted by comparing the effects of un-captured GDP measurement as demonstrated in Fig. A11. The result demonstrates no substantial differences between estimates with and without spline interpolation.

Aggregated prices *PA* are measured by the following equation: $P_A = \frac{P_T \cdot T_T + P_U \cdot U_T}{T_T + U_T}$

(2) Increase in the Emergence of Un-captured GDP Emerged by Uber

Similarly, no substantial differences in an increase in the emergence of un-captured GDP between estimated data with and without spline interpolation were confirmed as demonstrated in Fig. A12.

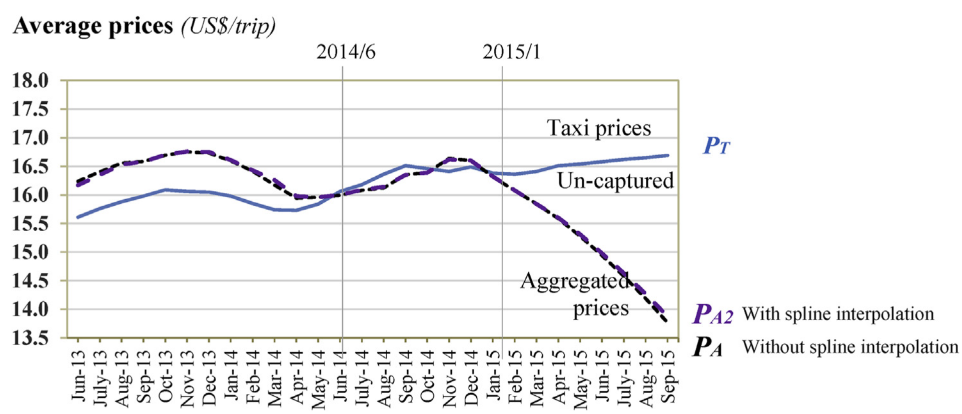
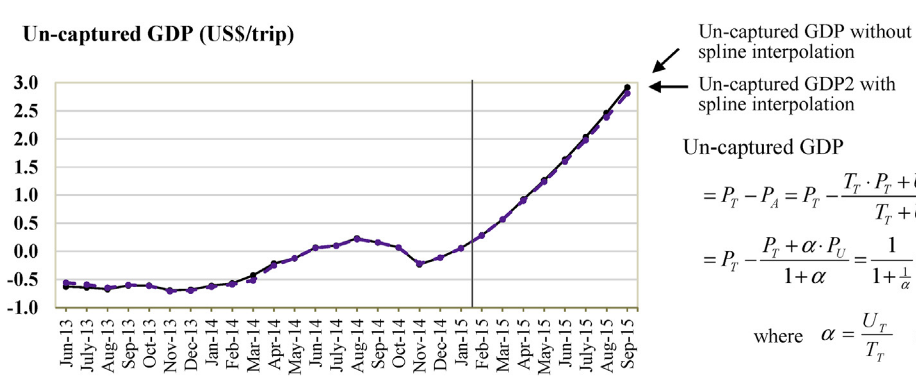


Fig. A11. Trends in Taxi Prices and Aggregated Prices in NYC *(Jun. 2013 – Sep. 2015)*.



Un-captured GDP

$$= P_T - P_A = P_T - \frac{T_T \cdot P_T + U_T \cdot P_U}{T_T + U_T}$$

$$= P_T - \frac{P_T + \alpha \cdot P_U}{1+\alpha} = \frac{1}{1+\frac{1}{\alpha}}(P_T - P_U)$$

where $\alpha = \frac{U_T}{T_T}$ *ratio*

Fig. A12. The trend in Un-captured GDP Emerged by Uber in NYC *(Jun. 2013 – Sep. 2015)*.

A4.3 Effects of Uber's Development Trajectory Estimate

While Uber's development trajectory, estimated using trips trend, without spline interpolation demonstrates the slight possibility of self-propagation by the LGDCC. Spline interpolation demonstrates explicit self-propagation by demonstrating the significance of the LGDCC.

While this difference does not have any significant effects on aggregated prices and un-captured GDP estimates, the effects on self-propagation can be attributed to a slightly higher pace (1–9%) of trips estimate after March 2015. This suggests that an optimal and not too rapid development pace seems essential for incorporating the self-propagating function.

Table A5
Estimates of Taxi and Uber's Development Trajectories in NYC by LGDCC

		N_k	a	b	a_k	b_k	adj. R^2
Taxi (2004/1 –2013/6)		2247.12	0.017	6.364	0.439	10.30	0.976
		(6.42)	(12.61)	(6.63)	(0.00^{x})	(0.00^{x})	
Uber (2013/6 –2015/9)	U_T	144.13	0.123	25.800	0.0001	3.04	0.992
		(2.95)	(12.68)	(3.29)	(0.10^{x})	(1.29^{*6})	
	U_{T2}	119.27	0.121	49.650	0.016	0.200	0.999
		(41.41)	(36.67)	(11.13)	(2.42^{*3})	(1.43^{*5})	

Taxi: based on medallion prices (Fig. 8), **Uber:** based on trips (Fig. 4) without spline interpolation (U_T) and with spline interpolation (U_{T2}) (See Table A4).
LGDCC: Logistic growth with dynamic carrying capacity, $Y = \frac{N_k}{1+be^{-at}+\frac{b_k}{1-a_k/a}e^{-a_k t}}$ (eq. (4)).
Figures in parenthesis indicate t-statistics: all significant at the 1% level except ^{*3}: 5%, ^{*5}: 15%, ^{*6}: 20%, ^{x}: non-significant.

Appendix 5. Uber's expansion in 375 cities worldwide (USA as of January 2016).

North America	North America	North America	North America	Central and South America
Abilene	Fayetteville, NC	Miami	San Luis Obispo	Barranquilla
Akron	Flagstaff	Midland-Odessa	Santa Barbara	Belo Horizonte
Albuquerque	Flint	Milwaukee	Santa Fe	Bogotá
Amarillo	Florida Keys	Minneapolis – St. Paul	Sarasota	Brasilia
Ames	Fort Myers-Naples	Mobile, AL	Savannah-Hilton Head	Bucaramanga
Ann Arbor	Fort Wayne	Modesto	Seattle	Cali – Colombia
Asheville, NC	Fresno	Monterrey	South Bend	Campinas
Athens	Gainesville	Montreal	Spokane	Cartagena
Atlanta	Georgia Coast	Myrtle Beach	Springfield, IL	Cucuta
Augusta	Grand Rapids	NW Indiana	St Louis	Goiania
Austin	Greater Maine	Nashville	State College	Ibagué
Bakersfield	Greater Maryland	New Hampshire	Stillwater	Lima
Baltimore	Green Bay	New Jersey	Tacoma	Medellín
Baton Rouge	Greenville, SC	New Jersey (Shore)	Tallahassee	Montevideo
Beaumont	Guadalajara	New Orleans	Tampa Bay	Panama, Panama
Bellingham	Hamilton	New York City	Taos	Porto Alegre
Birmingham, AL	Hampton Roads	Niagara Region	Tijuana	Rio De Janeiro
Boise	Harrisburg	Ocala, FL	Toledo	San Jose, Costa Rica
Boston	Honolulu	Oklahoma City	Toluca	Santiago
Bowling Green, KY	Houston	Omaha	Topeka	Santo Domingo
Burlington	Indianapolis	Orange County	Toronto	São Paulo
Central Atlantic Coast, FL	Inland Empire	Orlando	Tucson	Villavicencio
Champaign	Jackson	Ottawa	Tulsa	
Charleston, SC	Jacksonville	Outer Banks, NC	Tuscaloosa	
Charlotte	Kalamazoo	Oxford	Vancouver, WA	
Charlottesville-Harrisonburg	Kansas City	Palm Springs	Ventura	
Chattanooga	Killeen	Pensacola, FL	Waco	
Chicago	Kingston	Peoria & Bloomington-Normal	Washington D.C.	
Cincinnati	Kitchener-Waterloo	Philadelphia	Western MA	
Cleveland	Knoxville	Phoenix	Wichita	
Coeur D'Alene	Lafayette, LA	Piedmont Triad, NC	Wilkes-Barre Scranton	
College Station	Lancaster, PA	Pittsburgh	Wilmington, NC	
Columbia, MO	Lansing	Portland	Windsor	
Columbia, SC	Las Cruces	Portland, ME	Worcester	
Columbus	Las Vegas	Puebla	Yuma	
Connecticut	Lawrence	Quad Cities	the Hamptons	
Corpus Christi	Lehigh Valley	Quebec City		
Dallas-Fort Worth	Leon	Queretaro		
Dayton	Lexington	Raleigh-Durham		
Delaware	Lincoln	Reading, PA		
Denver	Little Rock	Reno		
Des Moines	London, Ont	Rhode Island		
Detroit	Los Angeles	Richmond		
Eastern Idaho	Louisville	Roanoke-Blacksburg		
Eastern North Carolina	Lubbock	Rockford		
Edmonton	Madison	Sacramento		
El Paso	Manhattan	Salt Lake City		
Erie	Maui	San Antonio		
Fargo	Memphis	San Diego		
Fayetteville, AR	Mexico City	San Francisco Bay Area		

Appendix 5. Uber's expansion in 375 cities worldwide (2) (Other countries than USA as of January 2016).

Europe	Europe	East Asia	South Asia	Australia and New Zealand
Amsterdam	Saint Petersburg	Beijing	Ahmedabad	Adelaide
Athens, GR	Sheffield	Changsha	Ajmer	Auckland
Basel	Sochi	Chengdu	Bangalore	Brisbane
Belfast	Sofia	Chongqing	Bhubaneswar	Canberra
Berlin	Stockholm	Dalian	Chandigarh	Geelong
Birmingham, UK	Strasbourg	Foshan	Chennai	Gold Coast
Bordeaux	Tallinn	Guangzhou	Coimbatore	Melbourne
Bratislava	Toulouse	Guiyang	Colombo	Mornington Peninsula
Bristol	Trojmiasto	Hangzhou	Guwahati	Perth
Brussels	Vienna	Hong Kong	Hyderabad	Sunshine Coast
Bucharest	Vilnius	Incheon	Indore	Sydney
Budapest	Warsaw	Jinan	Jaipur	Wellington
Copenhagen	Wroclaw	Macau	Jodhpur	
Dublin	Zagreb	Nanjing	Kochi	
Edinburgh	Zurich	Ningbo	Kolkata	

(*continued*)

Europe	Europe	East Asia	South Asia	Australia and New Zealand
Ekaterinburg		Qingdao	Mangalore	
Florence	**Middle East**	Seoul	Mumbai	
Geneva	Abu Dhabi	Shanghai	Mysore	
Genoa	Amman	Shenzhen	Nagpur	
Glasgow	Baku	Suzhou	Nashik	
Gothenburg	Beirut	Taichung	New Delhi	
Helsinki	Doha	Taipei	Pune	
Istanbul	Dubai	Tianjin	Surat	
Kazan	Eastern Province, KSA	Tokyo	Thiruvananthapuram	
Krakow	Jeddah	Wuhan	Udaipur	
Lausanne	Manama	Xi'An	Vadodara	
Leeds	Riyadh	Xiamen	Visakhapatnam	
Lille	Tel Aviv	Yantai		
Lisbon				
London	**Africa**	**South East Asia**		
Lyon	Alexandria	Bali		
Manchester	Cairo	Bandung		
Marseille	Cape Town	Bangkok		
Merseyside	Casablanca	Cebu		
Milan	Durban	Hanoi		
Minsk	Johannesburg	Ho Chi Minh City		
Moscow	Lagos	Ipoh		
Munich	Nairobi	Jakarta		
Nantes	Port Elizabeth	Johor Bahru		
Newcastle		Kuala Lumpur		
Nice		Manila		
Novosibirsk		Penang		
Oslo		Singapore		
Paris		Surabaya		
Porto				
Portsmouth				
Poznan				
Prague				
Rome				
Rostov-On-Don				

Source: Uber.com

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Chihiro Watanabe graduated from University of Tokyo, Japan and is currently Professor Emeritus of Tokyo Institute of Technology, Visiting Professor of National University of Singapore, Research Professor of University of Jyväskylä, Finland and also a Research Scholar, International Institute for Applied Systems Analysis (IIASA).

Kashif Naveed graduated with Bachelor's degree in Computer Science from Hamdard University Karachi, Pakistan, Master of Science in Economics and Business Administration from University of Jyväskylä, Finland, and currently doing his Ph.D. in Economics and Business Administration from University of Jyväskylä, Finland.

Pekka Neittaanmäki graduated from the University of Jyväskylä and is currently a Dean of the Faculty of Information Technology, University of Jyväskylä, Finland.