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RESEARCH ARTICLE

Disruptive Innovation on Two Wheels: Chinese Urban Transportation and Electrification of the Humble Bike

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Abstract

This communication argues that the electrification of the conventional bicycle could perhaps be a solution to the issues surrounding urban transportation in emerging economies. As illustrated through the trajectory of E-Bike development and adoption in China, such innovations can be disruptive when implemented in untapped mass markets of the developing world. A historical as well as prospective lens was adopted to describe the socio-economic significance of E-bike expansion in China. Further, by simultaneously considering the current Chinese urban transport mix, the primary energy use in transport as well as projections of future E-Bikes sales, it is also asserted that that, although the E-Bike is not an entirely sustainable solution to urban transport; it however is a solution that has the potential to achieve high sustainability. The realization of any environmental co-benefits due to the adoption of the E-Bike hinges primarily upon the adoption of improvements in other sectors of the economy (electricity generation). Indeed, the E-Bike does exemplify that grass-root, inexpensive and sustainable solutions to our urban transportation problems do exist.

Keywords

Electric bikes, Urban transportation, China, Disruptive technology, Sustainable transportation

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1 Introduction

In the present era of high environmental consciousness, deconstructing societal relations in the context of socio-technical innovations is imperative if we are to initiate a paradigm shift toward ecological modernization of our consumption behaviour (Spaargaren, 2003; Szendro, 2014). In an analysis of the electrification of US homes, Tobey (1996) points towards the dearth of interpretive research on consumer behaviour by elucidating how utility providers have operated on the assumption that household demand for electricity would be a function of their annual income with complete disregard for consumer individuality and buying habits. Investigating such relationships that bring consumption to the core of our discussions allow us to attribute greater importance to the role of citizen-consumers in shaping our institutions and in envisioning the cities of tomorrow (Simha et al., 2016a).

Critics have argued that the notion of sustainability does little to address and alleviate the problems of the developing world (Adams, 2008). While this has been true to a certain extent, it can also be argued that sustainability practitioners have failed to disseminate the appropriate type of innovative technologies to match the needs of what is largely, 'an untapped mass market', especially in the emerging economies of China, India and Brazil. What sets such markets apart is that, people here are in need of robust products that meet their basic requirements at ultra-low prices in line with their low incomes and relatively harsh living conditions (Dawar and Chattopadhyay, 2002). To tap this market while addressing the goals of sustainability, Hart and Christensen (2002) advocate innovators to go for a Disruptive Innovation (DI) approach, take a "great leap" downwards and exploit the non-consumptive market.

In this respect, sustainable transportation planning for urban areas is no exception. Conventional urban planning assumes that the progress in transportation is linear, and advocates newer, faster modes to replace older, slower ones. However, only when the dimensions of sustainability are integrated into this approach it becomes evident that, every mode of mobility has its own benefits and for improving urban transport (Levulytė et al, 2016), it is necessary to use each mode for what it does as it allows the establishment of a more holistic system (Litman and Burwell, 2006; Simha, 2016b). Following this corollary, in the societal response to the challenges of city traffic congestion, local air quality and energy security (Koryagin and Katargin, 2016) among others, it has been suggested that the *bicycle* could potentially play an invaluable role (Nemtanu et al., 2015). Keeping the consumer in mind, the performance of bicycles in relation to other available modes of mobility is significantly affected by the physical ability of the rider and his/her willingness to provide the energy needed to power it to the desired destination. However, the role of the bicycle in urban transportation could be expanded by the provisioning of power-assistance as this could address its limitations in trip distance as well as that of terrain (Dill and Rose, 2012). This in essence, is what the *Electric-Bike* (or *E-Bike*) offers; a new segment of vehicles that are propelled in part by human pedalling and in part, supplemented by electrical power, and/or low-speed bikes propelled entirely by electricity (with perfunctory peddles) (Weinert et al., 2007).

2 E-Bikes as disruptive innovation

To a large extent, E-Bikes can be considered a DI. DIs are defined as innovations that "*disrupt an established trajectory of performance improvement, or re-define what performance means*" (Christensen and Bower, 1996); a DI exhibits inferior performance in the attributes that mainstream consumers value but, at the same time gives a product new features that are appreciated by a new niche of customers (Christensen et al., 2001). In light of this description, the E-Bike is indeed a DI as it did not continue the technological progress of the trajectory of the bicycle or the motorcycle but redefined what performance is in the two-wheeler transport segment by adding an electric motor, a battery and a controller to a conventional bicycle. For the motorcycle manufacturers, the E-Bike was a low-quality product with meagre profit margin (6%) that was limited to a niche market not worth investing in (Ruan et al., 2014). However, since the early 2000s, the adoption of E-Bikes in China has significantly eroded the market share of motorcycle manufacturers who now face strong competition from well-established E-Bike firms that have satiated this new market.

3 A historical and socio-economic perspective

Since the founding of the PRC in 1949, bicycle production has been advocated as a national priority by the government. Biking in China thus, is nothing unfamiliar with most of its cities equipped with well-established bicycle infrastructure (Ruan et al., 2014). With growing population and traffic congestion dominating the political agenda, in 1991, the government named E-Bikes as one of the top 10 priorities and started investing in its R&D. This was further supplemented by the push for increasing energy efficiency in the mid-1990s gaining support from the then Prime Minister, Li Peng who called for the first national forum on E-Bikes to be held in 1996.

Industries like Daluge and Crane with government support rolled out their first lines of E-Bikes and created new market niches (women, elderly, disabled). This was followed by the adoption of an E-Bike National Standards (GB17761-1999) in 1999 that allowed provincial governments to start granting licenses to citizen-consumers. The government's strong push for E-Bike adoption is also seen in this period as many cities began banning motorcycles and/or granting new licenses for motorized 2-wheelers.

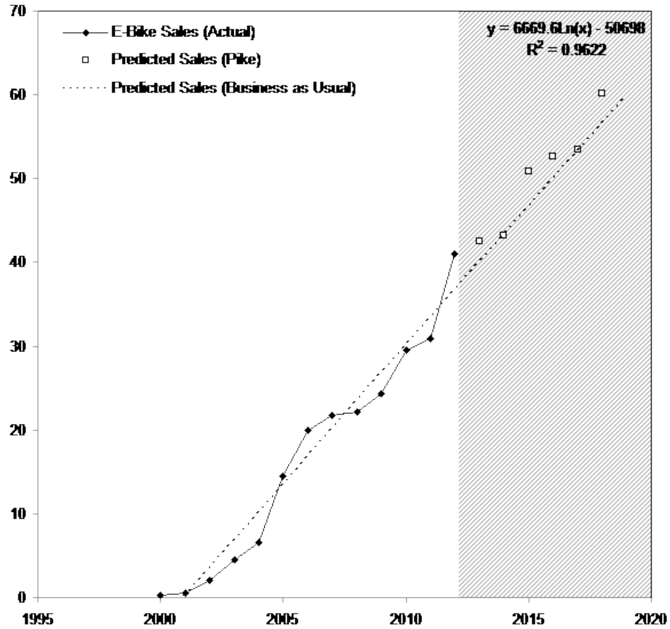

Fig. 1 E-Bike sales in China (values are in million units); illustration made by Author based on data sourced from ASKCI (2009) & NBS (2015).

Three stages in the industrial development and expansion of E-Bikes in China are evident; *emerging* (1995-1999), *mass production* (2000-2004) and *blow-out* (2005-present) (Yu et al., 2010). The focus in the emerging phase was on research and development of the four major component of the bike: motor, battery, battery charger and controller. In this phase, the firms collected information, adopted new technologies, initiated sales, and launched small test volumes for customer feedback. Here, the battery could support distances of 30 km.charge^{-1} with motor output of 14-18 NM that resulted into poor terrain-climbing capability. Wei Zhang, GM, Shanghai Cranes, sums this stage up aptly;

"*What we did at that time was using the basic structure of manual bikes, placed a 150 or 180-watt hub motor at the front wheel, installed a 24-volt, 7 ampere-hour lead-acid battery at the back seat, and last but not least, mounted the bicycle handle with a simple electronic controller*"

During mass production several key developments promoted the E-Bikes; among others, the ban on motorcycles in many cities, the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2002, and the continuous technological improvements in bike design such as Brush-Less Direct

Current (BLDC) Motors that motivated millions in China to shift their mobility preference. E-Bike firms seized this window of opportunity to establish several major and minor industrial clusters across the country.

The third stage is what the industry insiders call the 'blowout' as increasing competition among firms stimulated rapid technological development. This included a 35% improvement in battery life and capacity, a five-fold increase in the life expectancy of the electric motor with a 30% increase in its efficiency raising the climbing capacity by 3.5 times (Ruan et al., 2014). In addition, manufacturing costs dropped by 21% making the bikes accessible to a wider range of customers. In most cases it remains very unclear when a DI is perceived to be disruptive by the industry and when in a timeline it creates a new market niche for itself; however, this was very obvious in the case of China with E-Bikes outselling the gasoline powered motorcycles in 2005.

The most significant development however came in 2000 when the Department of State Transportation enacted the Road Transportation Safety Law which categorized E-Bikes as non-motorized vehicles (or bicycles). To be considered a bicycle, an electric 2-wheeler needed to be designed like a bicycle with functioning pedals, have a maximum speed of 20 $km.hr^{-1}$ and weigh less than 40 kg (Cherry, 2010). These criteria allowed E-Bikes to drive on the bicycle lanes and required no driving license or helmet to be worn.

As a state regulatory intervention, this law was revised in 2009 to impose more stringent safety measures (GB24155-2009); nevertheless, faced with protests from both manufacturers and consumers, the enactment of the law has been deferred contingent upon further revisions and debates (Ruan et al., 2014). Another unique feature in the trajectory of E-Bike adoption is seen in the role of provincial governments that promoted regional clustering of manufacturers which facilitated exchange of ideas (and technology), accelerated R&D and allowed for rapid commercialization (Dolfsma and Seo, 2013). Furman et al. (2002) in their framework for National Innovation Capacity also advocate the creation of such clusters to boost industrial competitiveness. Such governmental policies and regulatory interventions provide critical insight into the importance of empowering protective niches, like the E-Bike (Smith and Raven, 2012). Loop-holes in the Chinese transportation laws (intentional or otherwise) allowed both manufacturers and customers to fit and conform against the prevalent socio-technical pressures. It also helped them avoid the temptation of cheap gasoline in the market, a trend in the past year and initiate a transition toward greener modes of commuting (LaBelle, 2015). With over 1,200 E-bike manufacturers, 500 component producers, and 10,000 distributors that add up to a work force of over 5 million (Weinert et al., 2008), E-bikes in China are clearly a Disruptive Innovation which can no longer be easily ignored.

Figure 1 also illustrates two additional aspects of the Chinese E-Bike market; a continuance of the Business as Usual in this market will see sales of E-Bikes reach nearly 58 million by 2018. This is in line with a recent forecast by Pike Research (www.navigantresearch.com) which predicts the figure to be in the upwards of 60 million. Cumulatively, both the projections point towards a scenario wherein it is highly likely that China would have ~350 million electric powered 2-wheelers by 2018.

It is important to acknowledge that the rapid development of the Chinese economy in the past few decades has translated into increased per capita household incomes and improved standards of living. This when coupled with the trends of decreasing manufacturing costs of E-Bikes and the rising cost of gasoline helps explain the rapid diffusion and adoption of the technology bringing it within the reach of millions of people in China. Weinert et al. (2007) also point to the economic feasibility by showing that the cost of owning and operating an E-Bike is almost equal to the average annual transportation budget of a household (766 $RMB.yr^{-1}$). Moreover, for the entire lifecycle, E-Bikes exhibit the lowest cost among all the modes of personal transport available in China (Ni, 2006).

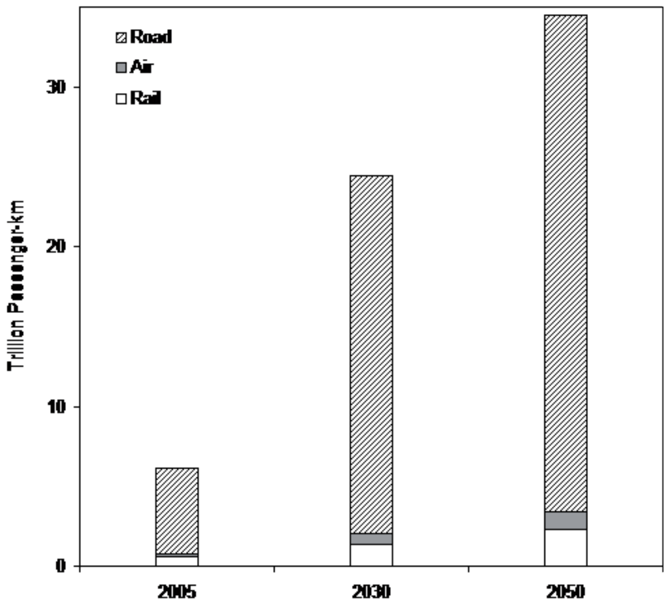

Fig. 2 Urban transportation mix in China; Illustration by Author based on data sourced from Zhou et al. (2011)

4 E-Bikes and sustainability

Certainly, the notion of sustainability has unknowingly become an obligatory imperative when it comes to both, planning for change as well as advocating for change in current system dynamics; it is perhaps the ease with which it can be applied that sees it being debated and deliberated upon in all societal functions. It is therefore unsurprising that the E-Bike has been promoted as a sustainable solution to issues surrounding urban transportation in China. As seen in Fig. 2, road transportation is the most favoured (87%) mode of urban mobility in China; with household incomes projected to rise and the inclination for such incomes to be translated as investments into personal ownership of vehicles, Zhou et al. (2011) predict road-based mobility to continue to dominate urban areas in 2030 and 2050. If as projected, a continued preference towards road transportation transpires in the years to come, it becomes all the more today that, improvements in efficiency of natural resources use (fuel, energy, raw material) as well as the usage of transportation product (bikes, cars) are adopted to counter the effects of the sheer increase in the magnitude of personal vehicle ownership in China. Certainly, relative to all other economic sectors, it is only the Chinese urban transportation that exhibits a growing share in oil demand and projected end-use; in a scenario of continued improvements to the current system, it is expected that transportation would account for 66% of the total oil demand (Zhou et al., 2011).

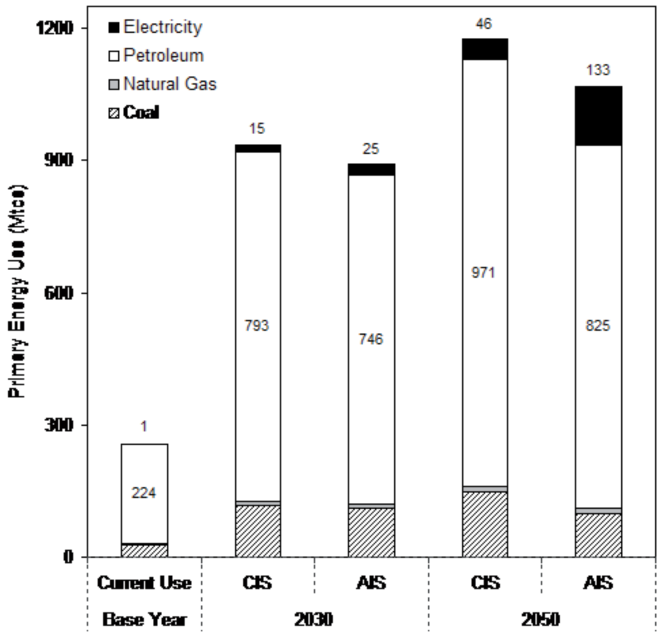

Fig. 3 Current and projected primary energy consumption by transportation sector in China; AIS: Accelerated Improvement Scenario, CIS: Continued Improvement Scenario; data source: Zhou et al. (2011)

Gasoline fulfills nearly all of the present primary energy demand (87.5%) in China. Hence, transportation has a considerable intra-sector potential for CO_2 mitigation if the sources of primary energy fueling the projected increase in electric vehicles on Chinese roads are sourced from less carbon intensive technologies or from renewable energy. However, nearly a third of the electricity in the country is currently generated in coal-power plants (76% in 2012); the sustained use of coal to fuel electric vehicles would counter any benefits arising from the use of the E-Bike. Nevertheless, there would be improvement in urban air quality in lieu of reduced localized emissions. It is promising to see that China has been aggressive in its investments into renewables; 2013 saw Chinese renewable energy investments outpace those in fossil energy. The New Policy Scenario (the IEA baseline scenario) of the World Energy Outlook (WEO) by IEA (2014) expects China to install an additional 960 GW of renewables by 2040 which would make up 55% of all the new energy investments. This would considerably alter the electricity mix to lower coal power dependency to 55% in 2040. Hence, it wouldn't be wrong to safely assume that decarbonization of electricity supply through sustained renewable energy expansion as predicted in the WEO and increase in the sale and end-use of E-Bikes for urban transport as assumed in the AIS scenario (Fig. 3) could result in significant environmental benefits. It is acknowledged that the E-Bike is certainly not a truly or even highly sustainable solution to urban transport. But it is surely a solution that has the potential to achieve high sustainability.

5 What does the future hold for E-Bikes?

Following the previous narrative, it becomes necessary to adopt a prospective lens to see what the future holds for E-Bikes. As Weinert et al. (2008) argue there could be two possible scenarios in the socio-technological trajectory of E-Bikes in China.

5.1 A shift towards E-Bikes

5.1.1 Technological improvements

Ever since its commercialization there has been a steady rate of performance enhancements in the E-Bike, especially in battery technology. Further innovation is likely to occur in the retrofit of advanced batteries to the bikes. Moreover, the E-Bike industry operates in an open-modular structure (Ge and Fujimoto, 2004) where manufacturers act as assemblers of modules procured from a decentralized source of suppliers. This 'open' structure allows suppliers freedom over design due to high modularity of the product, cross-pollination of innovative ideas, and increases competition which, in turn lowers price. Despite the emergence of dominant E-Bike designs, the industry has so far remained decentralized and this is critical for further innovations to occur. The improvements in battery design will hold key to realizing further environmental benefits of E-Bike use; in this vein, the regulation of the transition to Lithium ion batteries away from lead batteries will be imperative.

5.1.2 Product modularity

E-Bikes have the inherent modularity as key functions of the vehicle are performed by specific components (say, electric motor). This creates room for standardizing the components used in its manufacturing and could potentially allow for interchangeability among manufacturers and various bike models. This would also remove the barriers for entry of new players in the market such as bicycle and motorcycle producers in the E-Bike business.

5.1.3 Motorcycle bans

With local air quality being a high concern, nearly 148 cities in China have banned gasoline-driven motorcycles by 2006 (Sugiyama, 2003). For E-Bikes to continue increasing their market share it is imperative to avoid the temptation to switch back to gasoline which has witnessed a dramatic decline in price on the global market (Labelle, 2015).

5.1.4 Deteriorating public transportation

Rapid urbanization, population growth and rising incomes have led to the congestion of public transportation corridors in Chinese cities. This has been a prime factor in motivating a shift toward increased adoption of cheap, private motorized transport. With 40 million people projected to move into urban areas between 2006 and 2030, the sales volumes of E-Bikes could be expected to rise (Schipper and Ng, 2007).

5.2 A shift away from E-Bikes

5.2.1 Motorcycles et al.

In Asia, motorized 2-wheelers still remain the dominant choice for consumers due to their reliability, safety, speed and more importantly, long life and cheap initial capital investment. On the backdrop of rising fuel costs and air pollution concerns, motorcycle manufacturers have taken the initiative to control emissions, improve fuel economy and bring innovations in engine design. If the integration of these innovations is cost-competitive, E-Bikes will likely face stiff rivalry from the motorcycle segment.

5.2.2 Ban on E-Bikes?

As of date, 7 cities in China have placed a ban on E-Bike usage. The loopholes in the transportation laws have allowed manufacturers as well as users leeway in safety considerations. Loose enforcement has resulted in an increase in low-quality unsafe products to enter the market and an upsurge in the number of road accidents. Status-quo in the laws and their enforcement would result in more cities and provincial governments to ban the use of E-Bikes.

5.2.3 Better public transportation

An increase in the support (both financial and political) for public transportation could reduce the market for E-Bikes. Bus Rapid Transport with dedicated bus corridors have been built as demonstration projects in several major cities in China including Shanghai, Beijing, Hong Kong and Guangzhou. With the Government's five year plans indicating a strong push for enhancing public transit systems, E-Bikes adoption could face a decline.

6 Conclusion

The case of E-Bikes illustrates that there are several alternative routes to address the issues of pollution prevention and energy efficiency. While most developmental agencies and actors focus on promoting capital-intensive frontier technologies, the E-Bike stands out as a grass-root exemplar of disruptive technology dissemination. However, favorable policy implementation and regulation have a vital role to play as seen in the case of Chinese transportation policies. The industry itself is shifting gears to diversify their product portfolio to include 3-wheeler and 4-wheeler electric vehicles with the core of the technology coming from the E-Bike models. Moreover, as Giordano and Fulli (2012) point out in their Smart Grid Vision, establishment of Multi-Sided Platforms for E-Bikes could allow aggregators to bundle several value added energy services and shift the business perspective from supply to service provisioning.

For an emerging economy like China with roads filled with vehicular traffic and faced with severe urban air pollution, it is perhaps not surprising to see how a low-cost electric vehicle that could travel in bicycle lanes became popular. It however remains to be seen how the trajectory of the E-Bike adoption will be influenced by various forces at play in the near future.

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