First draft

Mobile Phones in Developing Countries

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I. Introduction

Mobile phone networks have been in operation for about 28 years. First introduced in Europe and Japan and in the U.S. in 1983, they have spread throughout the world in the past 10-15 years. In my 2002 paper on the mobile industry, I stated: "Mobile (cellular) telephone is an example of a new product that has significantly affected how people live."[2] At that time the effect of mobile networks was largely limited to well-off countries. Penetration is now rapidly increasing in even quite poor countries. For example in India where mobile penetration reached 44.7 per hundred inhabitants in 2009 increasing from 4.69 in 2004 for a growth rate of 57.0% per year over the 5 year period, handsets cost about US$25 while phone calls are about $0.01 per minute with text messages approximately the same amount. This outcome of the actions of the private sector with high competition among the 6-7 mobile operators in most parts of India contrasts with the dismal failure of government operation of the fixed line network with penetration of 3.2 per hundred inhabitants in 2008, a decrease from 3.8 from 5 years earlier in 2003. This pattern is common among LDCs worldwide: bureaucratic and sometimes corrupt operation of the fixed line network where it can take years to receive a connection compared to a highly competitive, low price private operation of mobile networks which is bringing near-universal connectivity to almost all segments of the population. Approximately 5 billion mobile phones are now in operation worldwide.

Recently, a ranking of new products put the internet, PCs, and cell phones as the top three innovations of the past 30 years.[3] Use of the internet in LDCs is typically quite low, in part

[1] Barrett Strickland and Gama Le Bouder provided research assistance. I had helpful conversations with Tony Atkinson, Avinash Dixit, Esther Duflo, and Arthur Lewbel. Please do not cite without permission.

[2] Jerry Hausman, "Mobile Telephone," in M. Cave et. al. eds, Handbook of Telecommunications Economics, North Holland, 2002, p. 564. The paper describes cellular technology and developments as of 2000.

[3] A panel from the Wharton School made the ranking. See http://query.nytimes.com/gst/fullpage.html?res=9D01E0D61E31F93BA35750C0A96F9C8B63&scp=2&sq=%22wharton%20school%22%20innovation%20cell%20phone&st=cse.

because of the lack of fixed line network penetration or cable network penetration. However, improved wireless technology in LDCs, including 3G and in a few years 4G and WiMax, will offer internet speeds of between 1.5mbs and 30 mbs. While downloading movies will be beyond the technology capability in the near future, advances in wireless health delivery in Mexico, India, Rwanda called mHealth programs are gaining rapid adoption.[4] Similarly, mPesa which is a mobile based banking network which allows inexpensive money transfer operates in Kenya. Money transfer using mobile phone exists in other countries in both Africa and elsewhere. This convergence in technology offer significant benefits to LDC populations who will have access to better information and reduced transactions costs. I will review some of these developments in this paper.

Another goal of this paper is to quantify benefits that arise with mobile networks in LDCs. I previous estimated that consumer welfare increased by $49.8 billion in 1994 in the US from cellular telephone and by 2000 this had increased to $111 billion.[5] I do similar calculations in this paper. For example in India, average monthly expenditure on mobile phones is US$5.68 which is 4.8% of income. So a significant amount of income goes to mobile usage. I calculate the Hicksian compensating variation to be $5.16 per month or 4.4% of income. Thus, mobile phones create a significant gain in consumer welfare. This convergence of technology among rich and poor countries has already brought significant benefits to LDCs with increasing benefits to occur in the future. However, I have not found many studies that quantify the benefits to consumer welfare of this convergence in technology. Yet the improvement in consumer welfare seems of the same order of magnitude or even large than many aid programs discussed in policy deliberations and in the development economics literature.

Lastly, I consider within country and between country welfare comparisons. A large academic and aid-agency, e.g. World Bank, literature has develop attempting to answer welfare-based question such as whether economic welfare has increased in LDCs and whether inequality has increased or decreased. This analysis considers GDP per capita, income per capita, or consumer expenditure across countries and over time and attempts to adjust them to a comparable basis using PPP (purchasing power parity) calculations. The PPP calculations are based on hundreds or even thousands of price comparisons at a minute level of consumer

[4] See e.g. "When you carpet calls your doctor", The Economist, ,April 10, pp. 65-66.
[5] Jerry Hausman, "Valuation and the Effect of Regulation on New Services in Telecommunications," *Brookings Papers on Economic Activity: Microeconomics, 1997,* and Hausman (2002) op. cit.

expenditure shares.[6] PPP's are basically multi-lateral price indices which inherit the problems of price indices in individual countries, especially in their incorrect treatment of new goods.[7] When mobile networks, or other new goods, become available to consumers in regions of LDCs where they were previously not available the welfare-based price decreases from the "virtual" price, which would cause demand to be zero, to the market based price.[8] The decrease in price is typically about 50% or larger, but this price decrease is not taken into account in either comparisons of a country over time or comparisons across countries. Indeed the usual comparisons are completely absent of any economic analysis but instead are based on the weighted averages of expenditure shares and prices.[9] In this paper I propose a method of analyzing consumer actions in terms of price elasticities and income elasticities to determine change in welfare and comparisons of welfare. Since at the most basic level, consumer welfare depends on their actual consumption choices, use of observed economic behavior may offer a better approach to measuring consumer welfare than the problems that arise in attempting to construct multilateral PPPs.[10]

II. Increasing Mobile Penetration

I first consider the extraordinary rapid increase in mobile penetration. The two largest countries with about 38% of the world population are China and India. Approximately 33% of the world's poor population live in China and India who have about 38% of the world population.[11] From 1998-2009 China's mobile penetration increased from 1.92 per hundred to

[6] See A. Deaton, "Price indexes, inequality, and the measurement of world poverty", American Economic Review, v100, n1, 5-34.

[7] I have discussed these problems in a number of papers. See e.g. J. Hausman, "Cellular Telephone, New Products and the CPI," *Journal of Business and Economics Statistics*, 1999 and "Sources of Bias and Solutions to Bias in the CPI", *Journal of Economic Perspectives*, 2003.

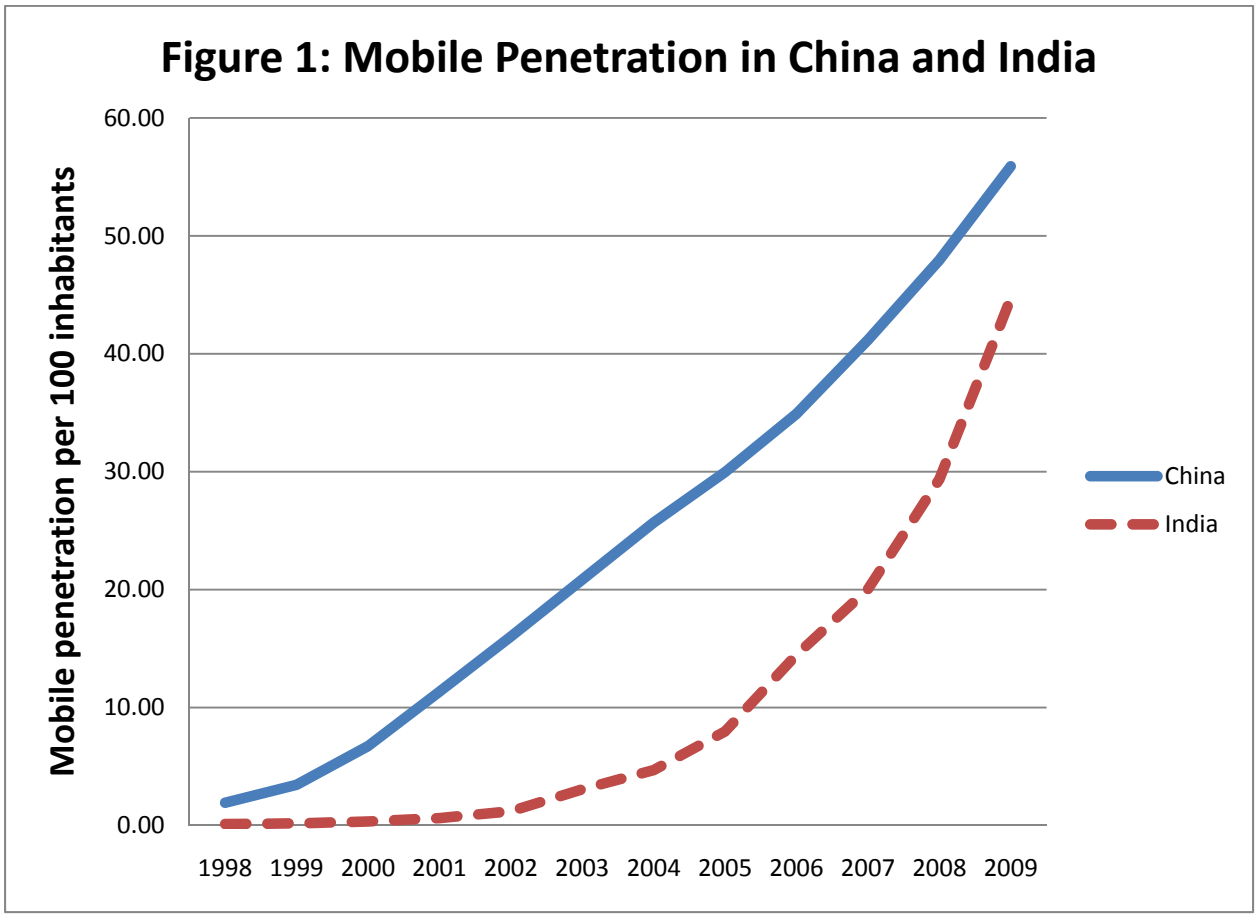
[8] See e.g. Hausman (2003) for a further discussion of the use of the virtual price for new goods.

[9] This statement is not quite accurate since construction of the weighted averages sometimes take account of the economic properties of the resulting indices using the idea of a "superlative" price index arising from E. Diewert, "Exact and superlative index number," Journal of Econometrics, 4, 1976. However, these considerations are "second order" as I describe in Hausman (2003) op. cit, and in practice do not vary much from Fisher geometric average indices which are based solely on their mathematical properties.

[10] S. Anand and P. Segal, "What Do We Know about Global Income inequality?", Journal of Economic Literature, 46, 2008, state that global inequality is of interest "as a measure of the distribution of goods or resources among individuals in the world." (p. 60) Observation of actual consumptions of goods may provide a better indication of real income that price index adjusted measure of per capita income.

[11] See e.g. Deaton (2010) op. cit., p.2.

55.9 per hundred. Over the same period India's mobile penetration increased from 0.12 per hundred to 44.7 per hundred. Mobile penetration continues to increase rapidly in both countries as Figure 1 demonstrates:[12]



Some care must be used in interpreting these penetration rates since businesses use mobile phones as well as consumers. Nevertheless, the rapid increase has been largely consumer based and, especially in India, much business-based mobile usage occurs small enterprises where individuals use their phones for both business and personal usage, as can be seen from the fixed line penetration of 3.2 per hundred, which has been decreasing.[13] Thus, consumers in China and India with 2008 average income per capita of approximately US$2940 and US$1070,

[12] Data Source: ITU (2009) and for 2009 data, http://en.wikipedia.org/wiki/List_of_mobile_network_operators_of_the_Asia_Pacific_region#China.
[13] Fixed line penetration has also been recently decreasing in China.

respectively, have decided to spend a significant proportion of these incomes, around 5% in India, on mobile phones.[14]

Increases in mobile phone penetration have occurred in most LDCs, although not with the same growth rates as in China and India.[15] Using ITU data I compare penetration across a number of LDCs in 2003 and 2008, a period during which the average price of a 2G handset decreased from approximately $US150 to US$75:[16]

Table1: Mobile penetration per 100 inhabitants

Country	2003	2008	2008 GNI US$	2008 Fixed Line
Algeria	4.54	92.72	4260	9.64
Angola	2.24	37.59	3450	0.63
Azerbaijan	12.84	75	3830	15.01
Bangladesh	0.92	27.9	520	0.84
Belarus	11.32	83.98	5380	38.41
Benin	3.21	41.85	690	1.19
Bolivia	14.47	49.82	1460	7.12
Botswana	24.79	77.34	6470	7.41
Cambodia	3.69	29.1	600	0.3
Colombia	14.83	91.9	4660	17.89
Congo	0.60	49.98		0.61
Cote d'Ivoire	6.94	50.74	980	1.73
Dominican Rep.	22.79	72.45	4390	9.9
Egypt	7.80	50.62	1800	14.64
Gabon	22.80	89.77		1.83
Ghana	3.80	49.55	670	0.62
Guinea-Bissau	0.09	31.75	390	0.29
Honduras	5.77	84.86		11.28
Kenya	4.71	42.06	770	0.63
Kyrgyzstan	2.74	62.69	740	9.13
Libya	2.23	76.71		16.41
Morocco	24.93	72.19	2580	9.46
Namibia	11.36	49.39	4200	6.57
Nicaragua	8.76	54.84	1080	5.51
Nigeria	2.34	41.66	1160	0.86
Pakistan	1.62	49.74	980	2.5
Peru	10.80	72.66	3990	9.98

[14] Source, ITU, "Measuring the Information Society", 2010, p. 58. The proportion of income spent in China for mobile service appears to be similar to India because mobile prices are higher in China than India. The ITU calculates the ratio of mobile price in China to prices in India to be 2.65 in US$ in 2009 and 1.58 on a PPP basis, p. 67.

[15] See J. Sandbach and L. van Hooft "Estimating the impact of telecommunications policies on mobile penetration and usage, 2009, for a discussion of the effect of regulatory policy on mobile penetration.

[16] 2G (second generation) handset are the predominant handset used in developing countries. Over this period the average price of 3G (WCDMA) handsets decreased from about US$580 toUS $170, with a high improvement in quality occurring.

Rwanda	1.50	13.61	410	0.17
Senegal	7.31	44.13	970	1.95
South Africa	36.81	90.6	5820	8.91
Sri Lanka	7.24	55.24	1780	17.18
Sudan	1.42	29	1130	0.89
Viet Nam	3.39	80.37	890	33.98
World	22.47	59.74		18.49

Notes:
GNI source: ITU paper, "2010 Measuring the Information Society"
Mobile & Fixed Line Penetration Source: ITU
2003 Population for "per 100" Source: World Bank

Growth rates have been in the range of 30%-50% per year or higher and penetration of mobile phones has increased rapidly. Mobile penetration has now far surpassed fixed line penetration in almost all LDCs and has become the dominant form of telecommunications.

III. Increase in Productive Efficiency Using Mobile Telecommunications

A number of academic papers and consulting reports, often sponsored by mobile operators, have identified increases in productive efficiency arising from the use of mobile telephones. One of the best known papers is the study of the fishing industry in southern India by Robert Jensen.[17] Jensen studied the fishing industry in the southern India state of Kerala. Prior to the spread of mobile phones, fisherman typically landed their catch daily at only one market, typically their local market. Using 1997 data he found wide variations in prices for sardines across markets and found significant existence of excess buyers with unfulfilled demand because of inadequate supply in some markets while excess sells occurred in other market leading to a price of zero and wasted catch. (p. 882)

When mobile phone became available in coastal cities in Kerala their range extended offshore to the fishing fleet. By 2001 Jensen reports that 60% of fishing boats and most wholesale and retail traders used mobile phones to help determine at which ports the fisherman should land than catch. Jensen finds that the advent of mobile phones led to an increase in fishermen's profits by 8%, a decrease in consumer price by 4%, and an overall increase in consumers surplus of about 0.06% of average household expenditure.[18] The

[17] Robert Jensen, "The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector", Quarterly Journal of Economics, 122, 2007.
[18] I have made this calculation based on data from p. 919ff. Consumer surplus in terms of sardines consumption increased by 6%.

increase in information arising from the use of mobile phone led to greater output and lower prices. Thus, the introduction of new technology in Kerala had a significant effect.

Jack and Suri (2009) have studied the use of mobile phones for money transfers among individuals in Kenya.[19] In 2008 Kenya had a mobile penetration of 42.1 per hundred with a growth rate of 59.3% per year. This penetration is about 77% of the population 15 years or older. Kenya's fixed line penetration is 0.63 per hundred and has been decreasing. Annual income per capita was $770 (2008US$). Three mobile operators compete in Kenya. In 2007 Safaricom, owned by Vodafone, the largest mobile phone company in Kenya, introduced M-PESA, which allows individuals to transfer money to other individuals as well as deposit and withdraw funds using their mobile phones. As of April 2010, M-PESA had 8.8 million customers in Kenya, 15,200 agents, and monthly transfers of $350 million with the average transfer about $30.[20] Vodafone estimates that 11% of Kenta's GDP moves through M-PESA. The service is now also available in Tanzania and has approximately 3 million customers. Vodafone is also launching the service in South Africa and Afghanistan in the first half of 2010.

M-PESA permits users to deposit money into an account which is stored on their mobile phone and to send money using SMS technology to other users as well as to redeem deposits at merchants for cash. M-PESA customers both deposit and redeem cash at M-PESA agents across Kenya. Customers also pay for goods and services from merchants. The Point of Sale (POS) at the merchant is a low cost mobile phone with a special SIM card. Thus, the merchant need not be hooked up to a nationwide network as is required for debit and credit cards.

The agent network has grown to 15,200 agents by January 2010. While volume on M-PESA is significantly less than in the traditional banking system, it is growing quite fast in part due to the relative scarcity of ATMs in Kenya. Jack and Suri report that as of September 2008, there were 107,000 transactions per day on M-PESA versus 180,000 transactions on ATMs. However, by January 2010 the daily transactions had grown to approximately 870,000 per day.[21] Thus, M-PESA had many more transactions than ATMs. The overall

[19] William Jack and Tavneet Suri, "Mobile Money: The Economics of M-PESA", MIT Sloan, October 2009.
[20] Vodafone presentation, "Vodafone Money Transfer", April 2010.
[21] Vodafone, ibid.

value per day of mobile was about 80% as large as ATMs.[22] Sending money via M-PESA is significantly less expensive than sending money via the Post Office Postapay system or via Western Union. Postapay is about 3 times the price of M-PESA while Western Union is about 2 times as expensive as M-PESA.[23]

In LDCs where straightforward transactions such as paying an electricity bill can entail travelling to a distant office and waiting in a long queue, M-PESA replaces this activity with an SMS message on a mobile phone. Also, family member who travel to cities to take jobs now have a safe and economical method to send money back to their families. Jack and Suri find that 72% of their sample sends remittances while 63% receive remittances. (p. 15)[24] The sending and receiving of remittances total about 5% of monthly consumption. Thus, M-PESA in a new good which permits lower cost transactions using mobile banking. For money transfers it is faster and lower price and in many instances both safer and more reliable. M-PESA provides a valuable additional service to the typical use of mobile telecommunications for voice calls, where the fixed line network in Kenya has failed o achieve any significant penetration.[25]

The World Bank has recently issued a report by Oxford Policy Management and the IRIS Center at the Univ. of Maryland on mobile banking in southern Africa.[26] Significant rural to urban migration as well as cross border migration exists in Southern Africa. Mobile penetration in 2008 in the countries considered in the World Bank report are:

[22] Jack and Suri (2009) report that about 72% of M-PESA users also have bank accounts. These individuals can also transfer money to their M-PESA accounts using ATMs.
[23] These comparisons are for transactions among registered M-PESA users.
[24] For non-M-PESA users the amount are 38% send remittances and 28% receive remittances.
[25] Also see I. Mas, "The Economics of Branchless Banking", Innovations, 2009 for further discussion of mobile phone banking.
[26] R. Stone et. al., "Trade in Financial Services: Mobile Banking in southern Africa", 2009, Report 50975.

Table 2: Mobile Penetration in Southern Africa

Country	2008 Mobile Penetration	2008 Income per Capita US$
Angola	37.6	$3,450
Malawi	12.0	$290
Mozambique	19.7	$370
South Africa	90.6	$5,820
Namibia	49.4	$4,200
Zambia	28.0	$950

For domestic branchless banking possible over mobile telephones Malawi, Mozambique, South Africa, and Zambia permit transactions within their regulatory frameworks. (p. 21) However, Angola restricts transactions. For cross border transactions only South Africa and Zambia permit transactions while Angola, Malawi and Mozambique do not permit them. However, the World bank report does no analysis of actual mobile banking networks in southern Africa. The best known network, WIZZIT in South Africa, has not had anywhere near the success of M-PESA in Kenya.

Mobile health care, "m-health", application are still largely demonstration projects.[27] However, some very successful projects have now been in operation for a few years. Toll-free information lines have been developed and projects such "Masiluleke" in South Africa sends SMS messages to provide information about HIV/AIDS and inform individuals about preventive measure.[28] A mobile hot line has been established to provide information about clinics and available test kits. High response has occurred in both South Africa and Uganda, which has a mobile penetration of 27.0. Data collection projects have given physicians mobile phones and they transmit information gathered while providing treatment and submit it to the ministry of

[27] For a discussion of the potential of m-health, see e.g. J. Kahn et. al, "The Relationship among economic development, Health, and the Potential roles of mHealth, 2008, S. Mishra, "mHealth: A Developing Country Perspective", 2008, and K. Ganapathy and A. Ravindra, "mHealth: A Potential tool for Health Care Deliver in India", 2008.

[28] See Economist, April 16, 2009, "A doctor in your pocket", http://www.economist.com/specialreports/displaystory.cfm?story_id=E1_TPQPSJVR&source=login_payBarrier.

health. Remote monitoring of patients is ongoing for TB patients in Thailand.[29] Compliance with TB treatments in China is monitored through free mobile phone usage.[30]

However, the greatest potential of mHealth is for remote diagnostics where nurses visit villages equipped with wireless transmission capabilities. Nurses do basic diagnoses and transmit medical information such as ECGs to central locations in urban areas where the information allows for a real time diagnosis. In Bangladesh the Alokito initiative has nurses go out to the field in specially-equipped vans to meet patients and perform basic procedures and transmit medical data to doctors in urban areas.[31] The doctors can ask questions of the patients and nurses and offer diagnoses. This project helps alleviate the pronounced shortage of doctors in rural areas of Bangladesh.[32]

IV. Increased consumer welfare from mobile telephone[33]

I have considered a number of applications of mobile technology, such as the use by fishermen in Kerala, which increase economic efficiency. Higher profits to fishermen increase economic efficiency. However, a much greater effect on consumer welfare occurs from the availability of mobile telephones to consumers. In the Kerala study the effect on consumers surplus from the lower price of sardines was only 0.06% of income. In this section I measure the consumers surplus and compensating variation from mobile phone and fine it to be approximately 100 times greater. I now measure this increased consumer welfare effect for India. To measure the increased consumer welfare I use an expenditure function (consumers surplus) approach using data from 19 Indian states collected in 2008.[34] The expenditure function approach answers the

[29] See http://www.aegis.com/news/ads/2007/ad070244.html
[30] See http://www.telegraph.co.uk/news/worldnews/asia/china/5088848/China-offers-free-mobile-phone-credit-in-the-battle-to-fight-tuberculosis.html and http://www.telegraph.co.uk/news/worldnews/asia/china/5088848/China-offers-free-mobile-phone-credit-in-the-battle-to-fight-tuberculosis.html
[31] See Boston consulting Group, "Towards A Connected World", September 2009, pp. 36 ff. and http://www.ericsson.com/thecompany/press/releases/2008/08/1242439
[32] Pilot projects are ongoing in many other areas including education and literacy and local early warning systems to provide information for national policy makers.
[33] This section follows Hausman (2002) where I estimated increased consumer welfare from mobile telephones in the U.S.
[34] The data are from R. Kathuria, M. Uppal, and Mamta, "An econometric analysis of the impact of mobile," in Vodafone, The Policy Paper Series, 2009.

following question: How much more (or less) income does a representative consumer require to be as well off in period 1 as in period 0 given changes in prices, changes in the quality of goods, and the introduction of new goods (or the disappearance of existing goods)? I first explain the theory and demonstrate how new goods should be included using the classical theory of Hicks (1940) and Rothbarth (1941) and then estimate the effect on consumer welfare.[35]

A. Economic Theory to Measure Increased Consumer Welfare

In the expenditure function approach, we need to know what the price would have been in the pre-introduction period. The correct price to use for the new good in the pre-introduction period is the "virtual" price, which sets demand to zero. Estimation of this virtual price requires estimation of a demand function that in turn provides the expenditure function, which allows exact calculation of the change in consumer welfare. Given the demand function I can solve for the virtual price and for the expenditure function (or indirect utility function) and make correct evaluations of consumer welfare from the introduction of a new product or service. In period 1 consider the demand for the new good, x_n, as a function of all prices and income, y:

$$x_n = g(p_1 ,..., p_{n-1}, p_n, y) \qquad (4.1)$$

Now if the good were not available in period 0, I solve for the virtual price, p^*_n, which causes the demand for the new good to be equal to zero:

$$0 = x_n = g(p_1 ,..., p_{n-1}, p^*_n, y) \qquad (4.2)$$

However, instead of using the Marshallian demand curve approach of Hicks (1940) and Rothbarth (1941) in equations (4.1) and (4.2), I instead use the income compensated and utility constant Hicksian demand curve to do an exact welfare evaluation and to calculate the compensating variation (CV). In equation (4.2) income, y, is solved in terms of the utility level, u^1, to find the Hicksian demand curve given the Marshallian demand curve specification.[36]

[35] This section is based on Hausman (1999a).

[36] In my subsequent calculations I find a noticeable difference between the Marshallian consumers surplus calculations and the theoretically correct Hicksian compensating variation calculations.

In terms of the expenditure function I solve the differential equation from Roy's identity which corresponds to the demand function in equation (4.1) to find the (partial) expenditure function, using the techniques that I developed in Hausman (1981). The approach solves the differential equation that arises from Roy's identity in the case of common parametric specifications of demand:

$$y = e(p_1 ,..., p_{n-1}, p_n, u^1) \qquad (4.3)$$

The expenditure function gives the minimum amount of income, y, to achieve the level of utility u^1, which arises from the indirect utility function, which corresponds to the demand function of equation (4.1) and the expenditure function of equation(4.3). To solve for the amount of income needed to achieve utility level u^1 in the absence of the new good, I use the expenditure function from equation (4.3) to calculate:

$$y^* = e(p_1 ,..., p_{n-1}, p^*_n, u^1) \qquad (4.4)$$

I could also use the pre-introduction utility level u^0 in equations (4.3) and (4.4). However, the effect would be small because of the relatively small percentage of expenditure on mobile telephone compared to income y.

Note that to use this approach one must estimate a demand curve as in equation(4.1), which in turn implies the expenditure function and the ability to do the exact welfare calculation of equations(4.3) and(4.4). Thus, the only required assumption is to specify a parametric form of the demand function.[37] I use two estimated demand equation for the price and income elasticity. Kathuria et. al. estimated a demand equation estimation in 2009 for India and Waverman et. al. in 2005 estimated a multi-country study for 38 developing countries using data from 1996-2003.[38] I give the elasticity estimates in Table 3:

[37] A non-parametric approach to the problem could be used with techniques developed in Hausman and Newey (1995).

[38] Kathuria et. al op. cit. and L. Waverman, M. Meschi and M. fuss, "The Impact of Telecoms on Economic Growth in Developing Countries", 2005.

Table 3: Price and Income elasticity estimates

Elasticity (t-statistic)	India (2008)	Waverman Developing countries (1996-2003)
Price elasticity	-2.12	-1.50
	(-10.34)	(-6.06)
Income elasticity	2.45	1.95
	(+15.1)	(+23.30)

Both econometric studies use instrumental variable techniques (3SLS or GMM) to take account of the joint endogeneity between mobile telephone demand and price. Both studies find similar results in that demand is price elastic, compared to inelastic demand typically found in developed countries. Both studies also find mobile telephone to have income elasticity exceeding 1.0 ("a luxury" good) which again contrasts with demand studies in developed countries. Lastly both studies find similar estimates, all of which are quite precisely estimated.

Estimation of the virtual price requires an estimate of the price at which demand equals zero. These data are typically unobservable and require extrapolation from the estimated demand curve. I also use an alternative conservative approach, which decreases the information requirements and provides a "lower bound" estimate. Once the demand curve is estimated, an approximation can be used by taking the supporting hyperplane at the observed price and quantities, (p_1, q_1), which then leads to an estimate of the virtual price of the lower bound linear demand curve to the actual demand curve. Now I claim that this estimate is conservative because the estimated virtual price from the linear demand curve will be less than the virtual price from the actual demand curve, unless the "true" demand curve is concave to the origin, which while theoretically possible would not be expected to occur for most new products and services. The change in expenditure to hold utility constant with the introduction of the new product, $y - y^*$, is the compensating variation which again can be approximated by the area under the approximate demand curve above the observed price. This amount is easily computed as:

$$y - y^* \approx CV = (0.5\, p_1\, q_1)/\alpha \qquad (4.5)$$

where CV is the compensating variation (consumers surplus) from the introduction of the new product and α is the own price elasticity of demand. To estimate equation (4.5) current revenue $R = p_1 q_1$ is required. Here I use data from the Kathuria study of India which uses 2008 data. The only econometric estimate needed is for the price elasticity α which I take from the studies summarized in Table 3.

B. Estimation of the Amount of Increased Consumer Welfare

I now turn to the econometric estimation to implement the expenditure function approach of equations (4.3) and (4.4) and the approximation approach of equation (4.5). To calculate the expenditure function of equation (4.4) I now use the results of Hausman (1981) to calculate the expenditure function for a log linear demand curve, which both studies summarized in Table 3 use for their econometric estimates:

$$e(p,\bar{u}) = [\,(1-\delta)(\bar{u} + A\,p^{1+\alpha}/(1+\alpha))\,]^{1/(1-\delta)} \qquad (4.6)$$

where A is the intercept of the demand curve, α is the price elasticity, and δ is the income elasticity estimate. The Hicksian compensating variation (CV) is calculated from equation (4.6) where y is income:

$$CV = \left\{ \frac{(1-\delta)}{(1+\alpha)}\, y^{-\delta} [\; p_1 x_1 - p_0 x_0 \;] + y^{(1-\delta)} \right\}^{1/(1-\delta)} - y \qquad (4.7)$$

I then use equation (4.7) to calculate the CV for the introduction of cellular telephone using the average revenue and subscribership data from the Kathuri et. al. study as well as the econometric estimates of the parameters of the demand function and associated expenditure function in Table 3.

I calculate that mean expenditure on mobile in India is US$5.68 per month and average expenditure is $118.30 per month so mobile expenditure is 4.80%. Using equation (4.7) and the estimates in the first column of table 3 to estimate compensating variation (CV), I find it to be $4.90 per month of 4.14% of expenditure. Thus mobile telephone creates a significant gain in consumer welfare in India. If I use the lower bound estimate of equation (4.5), I estimate the consumers surplus to be $1.35 per month or 1.1% of mean expenditure. If I use the alternative estimates in the right hand column of Table 3, I estimate CV to be $1.89 or 1.6% of monthly

expenditure. The results are summarized in Table 4:

Table 4: CV and consumers surplus estimates for India (2008)

	Karuthi	Waverman
Monthly Mobile expenditure	$5.68	$5.68
% of expenditure	4.80%	4.80%
Hicksian CV	$4.90	$10.39
% of expenditure	4.14%	8.78%
Lower bound CS estimate	$1.35	$1.89
% of expenditure	1.14%	1.60%

The virtual price which sets demand to zero for the log line demand curve is 15.0 times the current price (about US$0.01 per minute), which does not seem excessively high given the very low price of mobile in India. However, the virtual price for the lower bound estimate is only 1.48 times the current price, which seems too low. This result demonstrates how conservative the lower bound estimate is.

C. Welfare Estimation for Indian States

I next estimate the compensating variation (CV) for each Indian state and estimate it as ratio of income (GNI).

Table 5: CV Calculations for Indian States for 2009

States	Income, 2008 (Rs)	Penetration	CV (RS)	CV/Income
Delhi	67661	111.60	2823	4.2%
Punjab	44350	45.27	2256	5.1%
Tamil Nadu	36344	45.10	1705	4.7%
Kerala	39370	41.44	1891	4.8%
Himachal Pradesh	42785	39.29	1659	3.9%
Maharashtra	43681	37.46	1940	4.4%
Gujarat	41826	35.31	1838	4.4%
Karnataka	31001	34.12	2098	6.8%

Haryana	49193	31.90	1665	3.4%
Andhra Pradesh	32239	30.83	2029	6.3%
Rajasthan	20787	26.96	1527	7.3%
WB and A&N	28309	24.44	1242	4.4%
J&K	23943	22.32	1721	7.2%
North East	26789	18.80	1884	7.0%
UP	17036	18.33	1579	9.3%
Madhya Pradesh	22941	17.91	1463	6.4%
Orissa	21649	16.61	1396	6.4%
Assam	21700	16.18	1702	7.8%
Bihar	14113	12.21	1335	9.5%

I find a significant amount of CV and increased consumer welfare from the introduction of mobile telephone with the largest percentages with respect to income in the poorest states of Bihar, 9.5%, and UP, 9.3%. I find the mean across states to be 6.0% and the median to be 6.3%. Thus, I conclude that the increasing penetration of mobile telephone in India has led to significant gains in consumer welfare.

D. Welfare estimates for a Sample of LDCs

I next make similar estimates of other LDCs from Table 1 for which I was able to collect data on month mobile expenditure (ARPU). I apply the Waverman et. al. (2005) elasticity estimates and income data.

Table 6: CV Estimates Across Countries

Country	2008 Penetration	2008 GNI (US$)	Q4 2008 ARPU	CV/year	CV/GNI
China	48.0	2940	10.76	237.79	8.09%
India	29.4	1070	6.22	131.40	12.28%
Algeria	92.7	4260	10.62	240.90	5.65%
Angola	37.6	3450	26.50	538.99	15.62%
Azerbaijan	75.0	3830			
Bangladesh	27.9	520	3.67	75.61	14.54%
Belarus	84.0	5380	10.87	249.02	4.63%
Benin	41.9	690			
Bolivia	49.8	1460			
Bosnia and Herzegovina	84.3	4510			
Botswana	77.3	6470	13.00	297.98	4.61%

Cambodia	29.1	600			
Cote d'Ivoire	50.7	980			
Dominican Rep.	72.5	4390			
Egypt	50.6	1800	9.31	199.24	11.07%
Ghana	49.6	670	10.62	185.74	27.72%
Guinea-Bissau	31.8	390	11.00	158.76	40.71%
Kenya	42.1	770	6.44	129.30	16.79%
Kyrgyzstan	62.7	740			
Morocco	72.2	2580	11.15	243.02	9.42%
Namibia	49.4	4200	15.56	343.68	8.18%
Nicaragua	54.8	1080			
Nigeria	41.7	1160	13.01	247.25	21.31%
Pakistan	49.7	980	3.14	70.08	7.15%
Peru	72.7	3990	9.47	215.40	5.40%
Rwanda	13.6	410	11.00	161.92	39.49%
Senegal	44.1	970			
South Africa	90.6	5820	18.73	418.10	7.18%
Sri Lanka	55.2	1780	3.61	82.79	4.65%
Sudan	29.0	1130	12.96	245.12	21.69%
Viet Nam	80.4	890			
				mean	14.31%
				median	10.24%

I find significant gains in consumers surplus and compensating variation (CV) which measure the gain economic welfare from the introduction of mobile telephone in many LDCs. I estimate the mean of the ratio of CV/GNI (income) to be 14.3% and the median to be 10.2%. These large gains in consumer welfare have not received significant attention in estimating real income growth and changes in inequality in studies by development economists.

VI. Within Country and Cross-Country Comparisons

International agencies such as the World Bank and development economists often compare countries to determine whether growth is occurring and inequality is changing. While GDP or income in US$ can form the basis of comparison, most economists conclude that it is

better to deflate income by a price index relative to the US.[39] Purchasing power parity (PPP) price indices are typically used. However, construction of PPPs creates many problems which Deaton (2010) discusses because consumption across countries varies greatly. For example breakfast cereals are popular in many English speaking countries, while they are little consumed in French speaking countries.[40] Thus, the gathering of hundreds or thousands of prices of individual items undertaken in these studies poses significant index number problems. However, I find that another problem of construction of price indices and PPPs over time are that they do not take account of new goods correctly as I discuss in Hausman (1997, 1999, 2003). From Table 1 we see that mobile penetration has risen rapidly around the world. The price has decreased from the virtual price when mobile was not available in many geographic area of countries to the market price, which leads to a significant decrease in price. We also see that in India about 5% of income is spend on mobile which makes it a significant expenditure. This rapid spread of mobile has led to "convergence" in consumption across countries, but (to quote a phrase from my colleague Bob Solow) you can't find it in the real income comparisons.

In this paper I focus on actual consumption and economic behavior to construct a real income measure. My approach differs from PPP construction which are basically accounting exercises which take share weighted averages of prices, but incorporate no observed economic behavior. Instead I use observed economic demand for mobile phone to determine how to adjust income to put it on a comparable basis. To do so I make the usual (heroic) assumption of a representative individual with common tastes across countries. I use the log linear demand curve which arises from the expenditure function of equation (4.6):

$$q_i = A(p)_i^{\alpha}(y/\pi)_i^{\delta} \qquad (5.1)$$

where p_i is the price of mobile in country i and $(y/\pi)_i$ is deflated income where π_i is the (unobserved) price index. I solve for π_i which yields observed mobile penetration given the observed p_i and y_i. Then $(y/\pi)_i$ becomes the measure of real income based on mobile

[39] See e.g. S. Anand and P. Segal, "What Do We Know about Global Income inequality?", Journal of Economic Literature, 46, 2008 for a recent survey. A. Deaton, "Price indexes, inequality, and the measurement of world poverty", January 2010, mimeo discuss the many problems in constructing the price indices.

[40] Even within English speaking countries problems arise. Weetbix is popular in the UK, South Africa, Australia, and New Zealand but is not popular in the US or Canada.

penetration and the estimated demand curve.[41]

A. Estimated Real Income Index for Indian States

I first do this calculation for the states of India to adjust their observed income to put it on a "real income" basis. I use the state of Maharashtra, where Mumbai is the capita, as the basis of the comparison:

Table 7: Real income Calculations for Indian States for 2008

States	Income, 2008 (Rs)	Mobile Penetration	Income Index	Real Income Index
Delhi	67661	111.60	1.55	1.55
Punjab	44350	45.27	1.02	1.08
Tamil Nadu	36344	45.10	0.83	1.08
Kerala	39370	41.44	0.90	1.04
Himachal Pradesh	42785	39.29	0.98	1.02
Maharashtra	43681	37.46	1.00	1.00
Gujarat	41826	35.31	0.96	0.98
Karnataka	31001	34.12	0.71	0.96
Haryana	49193	31.90	1.13	0.94
Andhra Pradesh	32239	30.83	0.74	0.93
Rajasthan	20787	26.96	0.48	0.88
WB and A&N	28309	24.44	0.65	0.84
J&K	23943	22.32	0.55	0.81
North East	26789	18.80	0.61	0.76
UP	17036	18.33	0.39	0.75
Madhya Pradesh	22941	17.91	0.53	0.74
Orissa	21649	16.61	0.50	0.72
Assam	21700	16.18	0.50	0.71
Bihar	14113	12.21	0.32	0.64

Table 5 demonstrates a "convergence "of real income across Indian states when I adjust for mobile penetration. Richer states such as Haryana converge towards the mean while poorer states also converge towards the mean. The mean index increases from 0.75 to 0.92. At the extreme the unadjusted income has Bihar at 0.32 times Maharashtra, but adjusted real income finds Bihar increasing to 0.64. Not all states converge towards 1.0 as, for example, Tamil Nadu increases from 0.83 to 1.08 and Kerala increases from 0.90 to 1.04. Overall 12 states converge

[41] A. Young, "Real consumption Measures for the Poorer Region of the World" 2009, analyzes the demand for durable such as radios, TVs, refrigerators etc. but he does not have price data to adjust his measures.

towards the mean while 5 states diverge away from 1.0. The variance of real income decreases significantly relative to the variance of measured income. The variance of the unadjusted income index is 0.0931 while the variance of the real income adjusted index is 0.0414. Thus, measured inequality among Indian states decreases significantly when I make a real income adjustment.

B. Estimated Real Income Index for a Sample of LDCs

I now do similar calculations for a number of developing countries. I use China as the basis for the index.[42]

Table 8: Real Income Based on Mobile Penetration for 2008

Country	2008 Penetration	Mobile Price index	2008 GNI (US$)	GNI Index	Adjusted Index
China	55.9	1.00	2940	1.00	1.00
India	44.7	0.38	1070	0.36	0.91
Algeria	92.7	1.00	4260	1.45	1.22
Angola	37.6	1.69	3450	1.17	0.85
Azerbaijan	75.0	2.97	3830	1.30	1.12
Bangladesh	27.9	1.20	520	0.18	0.76
Belarus	84.0	0.36	5380	1.83	1.18
Benin	41.9	0.92	690	0.23	0.89
Bolivia	49.8	3.99	1460	0.50	0.95
Bosnia and Herzegovina	84.3	1.97	4510	1.53	1.18
Botswana	77.3	2.52	6470	2.20	1.14
Cambodia	29.1	2.18	600	0.20	0.77
Cote d'Ivoire	50.7	1.34	980	0.33	0.96
Dominican Rep.	72.5	3.09	4390	1.49	1.11
Egypt	50.6	2.30	1800	0.61	0.96
Ghana	49.6	1.12	670	0.23	0.95
Guinea-Bissau	31.8	1.15	390	0.13	0.80
Kenya	42.1	0.84	770	0.26	0.89
Kyrgyzstan	62.7	3.09	740	0.25	1.05
Morocco	72.2	0.77	2580	0.88	1.11
Namibia	49.4	5.98	4200	1.43	0.95
Nicaragua	54.8	3.44	1080	0.37	0.99
Nigeria	41.7	3.77	1160	0.39	0.89
Pakistan	49.7	2.80	980	0.33	0.95
Peru	72.7	0.28	3990	1.36	1.11
Rwanda	13.6	2.41	410	0.14	0.57

[42] For PPP calculations the US is typically used as the base. However, since I am considering developing countries and China is the largest, I base the calculations on China. The relative results would remain unchanged as the base does not matter.

Senegal	44.1	1.78	970	0.33	0.91
South Africa	90.6	2.24	5820	1.98	1.21
Sri Lanka	55.2	3.40	1780	0.61	1.00
Sudan	29.0	0.24	1130	0.38	0.77
Viet Nam	80.4	0.91	890	0.30	1.16

India increases its position significantly upwards compared to China, and a number of poor countries in terms of US$GNI increase significantly towards the mean; Bangladesh increases significantly from 0.18 to 0.76 so compared to India it increases from 49% based on GNI to 83% based on mobile penetration. A number of countries with higher US$GNI than China decrease towards the mean; Angola decreases from 1.17 to 0.85. Overall the mean index increases from 0.77 to 0.98, which is the expected direction of change since he sample contains a number of quite poor countries. The variance of the index decreases from 0.387 to 0.024 which demonstrates a significant decrease in inequality once the measure is based on actual consumption. These results are quite different from the PPP adjustment (using World Bank data) where the mean of the index decreases from 0.77 to 0.75 with a PPP adjustment and the variance decreases only a small amount from 0.387 to 0.321. Thus, mobile telephone usage demonstrates a much greater degree of real income convergence and a much lower degree of cross-country inequality than does the PPP data.

When I adjust measured income both across the Indian states and across developing countries, I find that the mean index increases significantly and the variance decreases. Thus, using mobile phone demand I find that people in poor countries are better off than indicated by their income measured in US$ and that inequality is less. I have made the usual representative consumer assumption, but the analysis might be better if done on micro-based survey data on individuals. I hope to do a project using micro data from India. Overall I conclude that using actual consumption data to measure inequality may provide useful information and may not encounter many of the problems that arise in making PPP adjustments.

VII. Conclusions

Of the 3 new products deemed to have had the most effect on the world in the past 30 years, the internet, PCs, and mobile phones, mobile phones have by far the largest penetration in developing countries. Mobile phones have provided widespread networks for voice

telecommunications where largely government operated fixed line networks failed to achieve widespread penetration. Competition among mobile providers has led to a far superior outcome than monopoly operated fixed line networks in most countries.[43]

As 3G and 4G become widespread in these countries, individual access to the internet will follow through the use of smartphones. Low price netbooks will also operate connected to the internet via either mobile or fixed wireless networks. However, smartphones may well make the use of netbooks unnecessary. For example, the iPhone uses the Mac operating system and an ARM processor so that it is actually a computer. With further chip integration and cloud computing, users may own only a smartphone which they can connect to a monitor and keyboard.[44] Currently, the reported component cost of an iPhone is about $250 so in the near future, I could see Asian manufacturers offering substitutes for about $50-$100 which could lead to wide adoption in developing countries at a significantly lower price than current netbooks. Thus, smartphones would be a low-cost source of computers in developing countries along with their communications capabilities. Mobile phone technology is a new product that has had profound effects in both rich countries and in poor countries and the technology may lead to widespread adoption of low-cost computers as well.

Applications of mobile phones also hold the promise of leading to significant improvements in productive efficiency by increasing producer information and reducing information costs. I expect the spread of mobile banking and remittances and bill payments to become widely available through the use of mobile phones. Also, for a number of years I have expected that transactions payments using mobile phones with adequate security arrangement would provide a relatively low cost debit type network for poor countries which do not have a fixed line network connecting small merchants to banks.[45] Perhaps the highest welfare improving potential arises with the use of mobile technology to improve medical care in poor countries. Nurses who visit rural villages will be able to communicate with doctors and nurses in urban medical centers, and the transfer of information should lead to improved patient outcomes.

[43] Some low and middle income countries have very high fixed line penetration where privately owned networks have used long distance revenues to cross subsidize fixed line access. However, these countries have chosen to have mobile competition which has worked well in these countries with high penetration rates.

[44] Smartphones also have an advantage with lower power consumption which reduces the requirement for connection to power grids which often create severe problems for laptops and netbooks in rural areas of developing countries.

[45] This type of outcome would also potentially overcome the problem that many individuals do not have bank accounts. Mobile phones could also be used in this way for a credit card type network

Lastly, I consider demand for mobile phones in developing countries. Mobile phones have led to a significant welfare improvement as my calculations for India demonstrate. Expenditure on a mobile phone in developing countries is often a significant proportion of total expenditure, on the order of 5%-10%. The relatively high penetration in developing countries demonstrates the high value that individuals place on mobile phones. When I consider the demand for mobile phones to adjust the calculated real standard of living I find that many quite poor countries have a demand for mobile phones which implies significantly higher real incomes than measured incomes in US$. My mobile phone measure of real income is not designed to be a final measure because demand for other products should be analyzed in determining real income across countries or within countries. Nevertheless, I see it as a first step to use actual observed consumer behavior to calculate real income, rather than using accounting-based measures such as PPP adjustment which have little or no economic basis.

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