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Techniques For Implementing Direct Road User Charges

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ABSTRACT

THE PURPOSE of this paper is to survey several alternative techniques which can be used to implement road user charges that vary by location, type of facility, time-of-day, and type of vehicle. The promising techniques available include supplementary licenses, road-side automatic vehicle identification techniques, on-vehicle meters, and load-sensitive meters.

There is a growing concern among transportation professionals and policy makers about the inadequacy of tax instruments used presently for implementing road user charges. Common instruments such as excise taxes, registration fees, and fuel taxes are regarded as too general and non-specific. They do not allow implementation of differential road user charges. Both equity and efficiency considerations suggest that the charges should vary by location (e.g., urban vs. rural), type of facility (e.g., Interstate vs. local street), time-of-day (peak vs. off-peak), and type of vehicle (heavy vs. light). Consequently, more precise and specific instruments are required. It has been argued that such instruments are not presently available. We believe, however, that some techniques are available or under development.

This paper surveys the technical features, implementation procedures and problems, availability, costs and the level of specificity achievable for the more promising instruments described earlier. The techniques are compared from the standpoint of costs and feasibility of implementing the different types of differential road user charges. It is suggested that the institutional, administrative and enforcement problems, and costs would generally increase with the increase in specificity.

The existing experience with these relatively new instruments is limited. On-vehicle meters that can be used in implementing road user charges that vary by distance and speed are used by taxis. The state-of-the-art is such that meters that would enable differential charges by location, type of vehicle, and time-of-day can be produced with short notice. Supplementary licenses such as those used in Singapore would allow charges to be varied by location, time, facility and vehicle, although exact precision may not be possible. Automatic Vehicle Identification techniques have been tested thoroughly at several locations, and hold the promise for implementing precise and specific user charges. Load-sensitive meters are in use in some European countries.

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INTRODUCTION

Traditionally, in U.S. and abroad, the charges for the use of roads have been implemented through excise taxes on vehicles and other automotive products, registration and license fees, and fuel taxes. These common tax instruments have been used widely around the world primarily because of the relative ease in administering them. Increasingly, however, the transportation community, and policy makers are beginning to recognize the shortcomings of these conventional tax mechanisms. They are much too general and non-specific. They do not allow implementation of differential road user charges that vary by the type and amount of use, by type of facility (e.g., Interstate vs. local collector street), location (e.g., urban vs. rural, or central city vs. suburbs), amount of congestion (e.g., peak vs. off-peak), dimension of vehicle, or vehicle loads (e.g., axle-loadings).

Such differential charges are desirable from the standpoint of both efficiency and equity since the travel costs and benefits vary across the many dimensions described above. For over twenty years economists have advocated the use of marginal cost or short run variable cost road user charges on the grounds of efficiency [Walters (1968)]. The current practice has been long recognized as inappropriate from the standpoint of efficiency both in congested (mostly urban) situations, and on uncongested roads due to the fact that different vehicle classes are not being charged prices equal to, or even close to, marginal costs [Bhatt (1976), Walters (1968)]. In addition, recent research suggests that the current road user charges are also inequitable [Bhatt et. al. (1977)].

Rational Road Use Charges

Rational and user charges can be developed on sound theoretical/empirical base. On congested (mostly urban) facilities, the road users could be required to pay the costs imposed by them (including the costs of delays and other externalities such as pollution). Of course, since costs imposed by each vehicle would depend upon location, type of facility, dimension of the vehicle, and level of traffic (time-of-day and/or season), the appropriate tax instrument must be specific enough to enable implementation of charges that vary across these dimensions. On uncongested facilities, the efficient policy might charge vehicles a price equal to the short run variable costs (as a proxy for marginal costs) [Walters (1968) and Bhatt et. al. (1977)]. Consequently, the tax instrument must be specific enough to differentiate use by axle-loadings and vehicle miles.

On uncongested facilities, efficient prices (short run variable costs) will generally not raise revenues sufficient to pay for all the expenditures made on the behalf of road users. Thus, if it is deemed desirable (on equity grounds) to balance the budget, then a second tier charge would be needed. Again, Bhatt, et. al. (1977) show that economic theory suggests a method of determining the second tier user charges which would maximize efficiency (the so called Inverse Elasticity method). However, the political decision regarding the choice of the second tier tax structure is likely to be more arbitrary. Any reasonable tax policy (except the very inadequate policy of charging prices in proportion to vehicle-miles) to balance the budget is likely to require user charges that vary by use and loadings.

In summary, none of the currently used instruments would be adequate for implementing the proposed user charge schemes which require much greater specificity. Even fuel taxes (which are use regulated) cannot be administered so as to differentiate adequately across the various dimensions described above. Consequently, alternative techniques for administering direct road user charges need to be considered.

Although differential pricing schemes can be developed upon reasonably sound theoretical base, a host of implementation, administrative and enforcement problems must be resolved before new techniques for instituting them can be used widely. The purpose of this paper is to survey several promising techniques that are currently being given serious consideration as instruments for implementing direct road user charges. This paper aims to identify the characteristics and potential of these more promising techniques as instruments for implementing differential, direct road user charges and compares them in different locations and situations where they are likely to be employed. Each technique has a unique set of implementation problems. Each shows a unique degree of difficulty in application of complex user charges that vary across the many dimensions described earlier. Also, with some of the techniques other problems such as invasion of privacy might also arise.

TECHNIQUES FOR IMPLEMENTING DIRECT ROAD USER CHARGES

The promising techniques for implementing direct road user charges which are presently available, or could be evolved quickly, fall into three categories:

- Supplementary Licenses for vehicles;
- Automatic Vehicle Identification (AVI) technology for off-vehicle scanning; and
- On-vehicle meters.

This paper assesses the characteristics and potential of each of these techniques as the road pricing instrument. These techniques are studied in terms of the feasibility and mechanics of implementing various types of road user charge policies requiring different levels of specificity, such as:

- policies in which prices vary by vehicle dimensions, road-type, location, and time of travel, as well as miles driven;
- policies that charge prices in proportion to some measure of output such as ton-miles or inputed revenues;
- policies where prices vary in proportion to some measure based on equivalent axle-load-miles operated; and
- strategies which comprise of some combination of the above three pricing policies.

These policies imply an increasing level of sophistication, and complexity in terms of the needed technology for implementation. Ease with which the four techniques described earlier can be adapted to administer this range of road user charge policies is the focus of this paper. Feasibility is assessed in terms of potential costs, ease of administration and enforcement; and the level of specificity.

Supplementary Licenses

Various types of special windshield permits can be used in implementing direct road user charges. The common theme behind this technique is to require different vehicles traveling at specific locations, on particular facilities, at certain times to display permits purchased in advance. Different levels of user charge can be handled by licenses that differ in color, number, shape, size, number and letter codes, and location on the vehicle. Consequently, a great deal of specificity can be achieved [Bhatt (1974), Bhatt, Eigen and Higgins (1976)].

Depending on the particular need, daily, weekly, monthly, or annual licenses can be used. Administration of annual licenses could be achieved easily much like the state registration plates or state safety inspection stickers. Monthly, weekly, and daily licenses could be distributed through common retail outlets (e.g., service stations, supermarkets, drugstores) in a manner similar to the sale of many state lottery tickets, or state fishing and hunting permits where the retailer get a percentage commission for participation.

The enforcement would require careful planning since moving vehicles must be monitored for misuse. Supplementary licenses could be checked for validity on a random basis. Of course, the licenses should have sharp colors to be spotted easily by enforcing personnel while the vehicle is in motion. Extensive studies in London [GLC (1974)] and elsewhere suggest that effective enforcement on moving vehicle is quite feasible provided stiff penalties and intensive monitoring are used to keep down the level of non-compliance. Moreover, if it is legally possible to send citations by mail to offenders, as in Singapore, enforcement would be quite simple.

Three major variations of daily licenses have been proposed in recent years:

- Date-specific licenses;
- Non-date-specific licenses; and
- Self-cancelling licenses.

The date-specific is the simplest license, designed to be valid for a specific day as indicated by the number/letter code printed on it. Since, it cannot be used on any other day, in addition to setting up a retail distribution outlet, a reimbursement system for refunds on prepurchased but unused licenses must also be set up. Singapore has successfully implemented a congestion pricing scheme using such licenses [Watson and Holland (1978)]. Since 1975, all low occupancy automobiles entering the downtown between 7:30 a.m. and 10:15 a.m. are required to display such daily stickers which cost about U.S. $1.60. They have faced no special administrative or enforcement problems. This location, time and vehicle specific user charge scheme works quite effectively. Several European cities, including London and Amsterdam, have developed plans to implement similar schemes.

Non-date-specific licenses do not carry specific date codes, and can be used on any day within a particular year, thus eliminating the need for establishing refund mechanisms. Reuse on another day is prevented by designing the licenses in such a way that the initial use sufficiently mutilates the license. Tel-Aviv, Sydney, Cork (Ireland), and many other cities use such licenses for controlling parking within core areas at particular times. Again, the administration and enforcement have been relatively easy. Although no local U.S. experience exists to date, Hermosa Beach and Santa Cruz in California will be soon implementing parking control schemes using such licenses. The local planners foresee few problems with administration or enforcement.

Currently under development are even more sophisticated non-date-specific, "self-cancelling" tickets which would use chemically treated surfaces to serve as time clocks. Such licenses would be activated by peeling off a protective cover or perhaps scratching it. This would immediately expose a certain color indicating that the ticket has been activated. At the same time a chemical reaction would start which after a predetermined time period (say 10 hours) result in a different color. The change in color would indicate that the ticket had "self-cancelled" itself. Such a scheme has the advantages of both previously described licensing schemes and does not require collection/refund system. Tickets with different "life periods" could be used effectively in complex pricing policies. The major requirements for such a ticket are that it should be completely insensitive to weather conditions and remain valid for the time period designated and change color abruptly at the end of the period. Unfortunately, this technology is still unavailable though preliminary exploratory research is now being carried out.

The current experience of Singapore, Tel-Aviv, and Cork suggests that the first two varieties above would cost no more than a fraction of a penny per sticker to print—if large quantities are ordered. Retail distribution costs have been estimated to be no more than five percent of the face-value of the daily licenses, nor more than 5 cents. More precise information on costs in a U.S. application will be forthcoming soon as Hermosa Beach and Santa Cruz demonstrations get underway.

In general, supplementary licensing concept appears quite attractive for implementing direct road user charges that vary only by location and time of travel, and vehicle type. In situations where the charges must vary by axle-load-miles driven, the licenses would not provide the level of specificity required. In situations where charges must vary by vehicle-miles, licenses would be adequate only if the average miles driven by each vehicle is relatively constant. Consequently, such licenses are most suited to administer congestion pricing in relatively small zones (e.g., central city areas), or on particular facilities (e.g., limited access highways).

The major advantage of this concept is that the licenses are available today, relatively easy to use, require very small investment, overall costs would be low, and pose little threat to privacy of individuals.

Automatic Vehicle Identification Technology (AVI)

AVI systems work by identifying vehicles as they pass a reference point (pricing point). The identification is achieved by off-vehicle roadside scanners which "read" a label or a coded signal permanently fixed on the vehicle. The pricing process operates without human intervention and appropriate charging and periodic billing is done automatically. The payment is via simple accepted methods similar to payment of utility or telephone bills. Thus, essentially this is a tolling device without a need to come to a stop or building toll booths. A variety of alternative technologies can be used for this purpose [Foote (1973, 1975), FHWA (1977)]. They include optical labels such as those on railroad cars which are scanned by the trackside camera, the use of laser beams, microwaves and low frequency induction. These technologies have undergone experimental tests in conventional tolling situations: an optical system was tested by the Delaware River Port Authority on their bridges outside of Philadelphia; the low frequency induction systems which use "black boxes" called transponders (with identification code) fixed on the vehicles and low frequency roadside scanners have been tested on a small fleet of buses in New York, New Jersey, and San Francisco.

Of all the AVI technologies mentioned above, low frequency induction technology appears to offer the best immediate alternative since the test installations suggest high reliability and great convenience. In contrast to other technologies, low induction method is much more reliable in adverse weather conditions, and where lateral vehicle movements within a lane are anticipated. The set up for this technology involves installation of an identifier on the vehicle (which carries the identification code and can either be a passive "box" activated via signals from roadside interrogator or could carry its own power source), an interrogator (scanner) at the roadside at each pricing point, an induction loop in the roadbed for each lane, and communication channels to a central computer that processes the information. All components can be produced and installed in large numbers within a few months according to several manufacturers.

Once installed, the AVI system can be essentially administered automatically through a small staff of maintenance, processing, and billing personnel. The enforcement would include only a periodic check (much like the state safety inspections) to test for malfunction. In fact, the interrogator would also be able to identify the malfunctioning units if it started receiving false signals. The transponders can be mounted on the undercarriage of vehicles in a temper-proof box to avoid fraud.

Unlike supplementary licenses, AVI system would require considerable investment in roadside equipment. Bhatt (1974) estimated that roadside equipment might cost around $10,000 per lane to install and would have a life of perhaps 8 to 10 years. In addition, the transponders on vehicles would cost approximately $25 per unit if mass produced. They would have a life of 5 to 6 years. The operating costs would include roughly $2,000 per year per pricing point for maintenance, $5 per vehicle per year for administration and enforcement, and $50,000 and $100,000 per year for central processing. All in all, although AVI system would require initial investments, the overall costs probably would not be exhorbitant, provided the system is used to administer road user charges for several years.

In summary, since these technologies allow identification and imposition of charges to be accomplished automatically on moving vehicles as the traffic smoothly passes by the pricing points, some of the queuing problems, space requirements and expenses of manual toll collections method can be avoided. Low induction AVI is also relatively fraud-proof and its proper use is easily enforced since the small identifier can be mounted on the vehicle frame underneath and locked in a tamper-proof box. AVI does not require driver involvement and distraction while the vehicle is in motion.

Again, as with supplementary licenses, AVI system would be most appropriate for implement road user charges that vary by location, and time of travel and vehicle dimensions (e.g., congestion pricing). In fact, it could provide greater specificity than licenses in situations where it is deemed desirable to vary charges very precisely over the time dimension in response to suddenly changing congestion, since appropriate charges can be added to user's account kept in central computer file. AVI would not be appropriate, however, if the charges must vary with axle-load-miles driven. Even where charges vary with simple travel measures such as vehicle-miles, AVI would be useful only if the priced zone is small or constrained in such a way that the miles driven by each vehicle can be accurately estimated externally. Over larger areas, the effectiveness would require an excessively large number of pricing points in order to measure vehicle-miles accurately.

There are some important factors which might undermine acceptability of AVI, even where road user charges do not vary greatly by miles. The heavy initial investment in equipment make AVI systems relatively unattractive if the system will not be used for many years on a permanent basis. Another major concern relates to the invasion of privacy which such systems threaten to permit since vehicles can be automatically identified and traced. These objections could be addressed by destroying the information about time and place of charge as soon as it has been processed and the appropriate user file updated, much as the telephone company treats message units. However, this may not be feasible—the public may actually desire to receive detailed invoices such as the long distance telephone bills since the charges are likely to be substantial.

On-Vehicle Meters

Four types of on-vehicle meters are either available or have been proposed to facilitate implementation of direct road user charges:

- Drivers actuated time/distance meters;
- Automatic time/distance meters;
- Driver actuated or automatic "time clocks"; and
- Load-sensitive meters.

These meters could be mounted inside or outside of the passenger compartment to measure the quantity (time, distance, load-miles, etc.) which can be used to impose charges appropriately.

Driver Actuated Time/distance meters are used extensively by taxis. Typically, the mechanical meters sell for around $200-$300 while the new electronic meters sell in the range of $500. They are expected to last five or more years. The costs of electronic meters would likely decrease substantially with advance in micro-electronics and mass production. Even then, the costs over the near future are likely to remain relatively high compared to licenses or AVI. More important, the current taxi meters cannot be used if more than two road user charge levels are required across different zones or facilities. On the other hand, since unlike supplementary licenses of AVI systems, meters allow vehicle-miles to be measured quite accurately, charges that vary with miles driven can be instituted very precisely. Thus, for example, such meters would be most suited to implement congestion pricing scheme where charges depend simply on the mileage driven.

The administrative requirement for using such meters for implementing direct road user charges would consist mainly of overseeing proper installation, and periodic checks to test proper operation, and for accounting and billing purposes, much like the metered-mail accounting. Moreover, enforcement of proper use would require the activated meter to be designated by a pilot light clearly visible from outside so as to avoid noncompliance.

Automatic time/distance meters would be useful in situations similar to the ones in which manual meters are appropriate. The advantage of automatically triggered meters over the manual variety would be that the operator is not distracted while driving the vehicle. Moreover, the enforcement problem would be reduced since the drivers would not be able to avoid activation. Unfortunately, meters which can be activated automatically with a command signal from a road side device placed at appropriate locations are currently not available. However, the current state-of-the-art relating to the electronic meters should enable rapid development of such meters in the near future.

Automatic meters that measure time/distance of vehicle movements called "chronotachygraphes" are used widely in France (nearly half of the heavy vehicles are equipped with them). These mechanical devices are installed in the vehicles and connected to the transmission. The devices are equipped with styluses and record the speeds and distances on disks or paper tapes [Ribat (1975)]. The European Economic Community has recently adopted this system to regulate truck operation time and speed. Unfortunately, little data about the costs, infractions, or administrative problems are presently available. Also, since these devices cannot differentiate among travel on different facilities or locations, they are not suited for congestion pricing policies. They would be appropriate only for implementing user charges which vary simply with the distance traveled and speed. In this regard they certainly would be much better than fuel taxes.

"Time clocks" differ from the above mainly in the fact that they measure only the duration of travel. Consequently, they would be appropriate for even fewer user charge policies than the others. On the other hand, however, the "time-clocks" are likely to be much less expensive to produce and maintain. Furthermore, as suggested by The Ministry of Transport (1964) it is feasible to produce meters that can work at several different speeds, and thus enable multiple road user charge rates to be implemented quite easily. The administrative and enforcement procedures for implementing road user charges with such "time-clocks" would be very similar to those for time/distance meters described earlier.

The Ministry of Transport (1964) described several alternative "clock" mechanisms. The first type consisted of devices that would require activation by the driver who must trigger the meter at a rate consistent with the charge for the zone and time of use. These could either use a simple clockwork mechanism or use electrolytic timer which must be inserted into the device to trigger it. Such a timer would function like a special battery activating the meter for some set period of time before expiring, at which time the timer must be replaced with a new unit and the used timer would be discarded. Some versions would use a cassette which could be traded in for a new one when it "runs down." The used cassette would then be "re-charged" by the authorities. The second type included meters that would be activated automatically as the vehicle enters congested zones. A signal from a road loop would trigger the device. These could register charges in discrete jumps where the signal from the road loop would discretely advance the count on the meter every time a pricing point is crossed. Alternatively, the road signal would activate the meter which runs continuously until deactivated by another signal or a manual override.

It was estimated that the costs of using such meters for road pricing would be quite reasonable. The meters could be mass produced for $10 to $20, installed for $20, and last five years or more. The cassette timers could be produced for 10¢ to 20¢ and also last five years or more. The roadside signalling device and the under-pavement loops could be installed for as little as $300-500 per lane pricing point. Finally, the major administrative cost would be for the retail distribution of timers which could be done in a manner and cost similar to that described earlier for licenses.

Since meters that do not use pre-paid timers would have to be presented periodically at special depots for adjustment and billing purposes, the "clocks" which use pre-paid electrolytic timers activated automatically via a roadside command signal appear to hold the greatest promise. The charges can be varied conveniently (say by time-of-the-day, or location) by simply adjusting the roadside signal strength and having the meter respond accordingly. Unfortunately the timers are far from the production stage at the present. They also present many opportunities for fraud and misuse. Over the long run, however, on-vehicle meters show good promise and could turn out to be quite an inexpensive way of implementing pricing policies that vary by location, time-of-the-day, and vehicle type. Once developed, like AVI, they would allow pricing policies to have wide coverage with few loopholes. They would allow implementation of charges that vary by time duration of travel. In this respect these "clocks" would be more specific than either the licenses, or the AVI.

Existing **load sensitive metering devices** measure either the gross vehicle weights, payloads or axle-loadings. For example, ELDEC Corporation of Lynnwood (Washington) makes on-board electronic scales which provide a digital read-out of total and, individual axle loads. The device consists of bar-like load cells, placed at load stress points on the hauling rig [HDT (1977)]. However, the installation requires some modification of the chassis. Consequently, installation or existing vehicles might be costly and time consuming. The device is claimed to provide accuracies of within one percent under the most stringent conditions. Unfortunately, little empirical data are available. The device has been used primarily in logging operations. Also unknown is the sensitivity of this analogue device to ambient disturbances. This scale is reportedly sold by ELDEC for about $2500.

More significant from the standpoint of direct user charge policies is the so called ATON-system marketed by Nordisk Electronik AB, of Sweden. ATON load-indicator is based on a new sensor technology and microcomputer electronics. Small sensors are spot welded rather easily on to the axles or other load-taking parts. An instrument in the cabin displays axle-loads, gross weight and payloads by pressing some buttons. This system is widely used in Sweden by private fleets, and state and municipal authorities [NE.AB. (1979)]. Swedish government is currently evaluating the device before recommending its mandatory use.

It is easy to install the device on new or old vehicles and is claimed to be very accurate. Importantly, although not currently available, the output could be processed easily in many different ways (e.g., on a paper tape). It would be possible to integrate load figures while the vehicle is in motion with the odometer output. This would enable direct recording of load-mile measures. Thus, in principle, it could be easily modified to automatically record equivalent axle-miles driven by each vehicle so equipped. Currently, the device costs approximately $1300 to purchase and install, but the prices would be expected to drop substantially if mass produced, and with the developments in micro-electronics.

Such load meters, particularly the ATON device, can be used very effectively for implementing road user charges that vary in proportion to ton-miles, axle-miles, equivalent axle-miles, or other output based measures. If only certain vehicles (e.g., heavy trucks that contribute an overwhelming percentage of equivalent axle-miles, and related damage to roads) were to be equipped with such meters, the costs would be quite reasonable.

Such meters would not be appropriate, however, for implementing charges that vary by location or type of facility. The time-of-day could perhaps be incorporated by integrating a timing device with the load-meter. The variability by location can be achieved only if roadside interrogators can be set up that automatically pick-up the axle-load data from the device as the vehicle passes by.

SUMMARY

Preceding discussion suggests that several alternative instruments for implementing direct road user charges are available today. In addition, many others are technologically feasible in near future. Even for the readily available instruments discussed earlier, little U.S. experience exists. However, feasibility of these concepts are being evaluated through literature reviews, and field tests. All available information suggests that these instruments hold great promise for successful application. Differential user charge policies can be administered and enforced. In spite of significant annual costs associated with the use of these techniques for implementing road user charges, they would generally represent only a tiny fraction of the user charges imposed, and revenues generated. Moreover, the overall benefits of greater efficiency and equity would almost certainly outweigh the costs.

Each technology described has its unique problems of enforcement and administration, costs, and requirements of initial investments. Also, the level of specificity that can be achieved with each instrument, and hence, the appropriateness for implementing a particular user charge policy differ significantly. However, these technologies would still allow effective implementation of most desirable user charge policies. These rational road user charge policies will require a level of specificity that is reasonably within the capability of the techniques described. At the same time, currently used tax instruments (excise, registration, and fuel taxes) are not sufficiently specific.

Recent studies suggest [Bhatt et. al (1977)] that for uncongested roads, desirable user charge policy (from both efficiency and equity standpoints) would require a two tier tax structure. The first tier would charge vehicles in proportion to equivalent axle-miles (axle-miles) weighted by a fourth or similar power of axle-loadings) to account for the relative road damage done by each vehicle. In addition, since the first tier charges are not likely to generate sufficient revenues to meet all the road expenditures made on these roads, a second tier tax will be necessary. The second tier tax will most probably be based on user charges in proportion to some measure of output deemed most equitable, or user charges based on Inverse Elasticity rule [Bhatt et. al. (1977)] to maximize benefits. Both of these taxes would require the use of load-sensitive meters described earlier.

For congested roads, a rational policy would be to charge vehicles in proportion to the marginal costs including costs of delays, pollution and other externalities (congestion pricing). While, in principle, congestion levels vary greatly by location, facility and time and would require prices that vary infinitely across time and space, for practical purposes it would generally suffice to consider no more than two or three charge levels in a particular city. Consequently, while none of the technologies surveyed in this paper can be perfectly specific, all except load-and time/

distance-meters could be used quite effectively in implementing congestion pricing. Of these, supplementary licenses probably hold the greatest near term promise, since their use would require fewest changes in existing institutions and practices.

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