Promoting Sustainability:
Exploring the Role of Expressive, Indirect, and Hidden Markets

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Abstract

By midmorning, the vendors are out. They pedal through the alley on three-wheeled carts, each announcing his product with a trademark cry. The beer woman is the loudest, singing out again and again, "Maaaaiiiii piiiiijiuuuuuu!"... The rice man's refrain is higher-pitched; the vinegar dealer occupies the lower registers. ... The sounds are soothing, a reminder that even if I never left my doorway again life would be sustainable, albeit imbalanced. I would have cooking oil, soy sauce, and certain vegetables and fruit in season. In winter, I could buy strings of garlic. ...

On an average day, a recycler passes through every half hour, riding a flat-bed tricycle. ... Not long ago, I piled some useless possessions in the entryway of my apartment ... A stack of old magazines sold for sixty-two cents; a burned-out computer cord went for a nickel. Two broken lamps were seven cents, total. A worn-out pair of shoes: twelve cents. Two broken Palm Pilots: thirty-seven cents.

— *Hutong Karma. The many incarnations of a Beijing alleyway*, by Peter Hessler, The New Yorker, February 13, 2006.

Bringing the hutong spirit to America? Peter Hessler describes the experience of living in an alleyway in Beijing, and about the many small transactions that support the daily life of residents. Can we bring this vision of sustainability to our own busy lives through a careful, but deep embedding of computation and markets to coordinate a multitude of little decisions that taken together could be quite transformative?

We see already small steps. Carsharing and carpooling, through services such as *Zipcar* and *Zimride*, are freeing what for many of us is a significant wasted resource that sits idle at home or at work for many hours of the day. But what if we could find a way to adopt optimization and dynamic pricing to enable cars to be used for one-way trips, with appropriate incentives provided to keep the supply and demand of vehicles in different locations balanced? Similarly for bikes. There are times in the day in some European cities with bike-sharing schemes where there are no bikes available. What if the price to rent a bike was dynamic so that high value use is sustained throughout the day?

Consider progress towards *smart grids*, which combine distributed energy generation (e.g., solar cells, wind turbines), distributed storage (e.g., with electric cars), and digital technology to control consumer appliances. Smart grids promise to make our electricity production more environmentally friendly and our electricity consumption responsive to marginal rather than average prices, with time-shifting and demand reduction occurring based on overall welfare considerations. But in making smart grids a reality we need technology that can hide the complexity of the market as much as possible from users and elicit preferences in order to manage the many little decisions that would need to be made throughout the day.

Swap markets such as the *Harvard Reuse List*[1] are emerging, where members of a community (in this case Harvard students and staff) can swap office supplies, furniture and other used surplus items. Harvard's swap market was sparked by the observation that many college goods are only desired temporarily (e.g., course textbooks and furniture), with an opportunity to make the entire community better off by finding useful trades and boosting resource efficiency. Currently the Harvard Reuse List operates without using optimization to find matches. Could a market be made "thick"— with lots of trades identified —by adopting a bidding language where every participant must point to *multiple* acceptable goods and bring a good (or a friend with a good) to the market? This problem then becomes similar to that of matching recipient-donor pairs in kidney exchanges [1].

In thinking about computational sustainability, it would be silly to neglect the massive amount of energy consumed by data centers.[2] One response to this is to move more computing from data centers into

[1] The Harvard Reuse List was developed by Henry Xie, a Harvard student, in partnership with Harvard Strategic Procurement and the Office for Sustainability (OFS). A requirement for its deployment was that there not be any money involved. http://green.harvard.edu/reuselist

[2] In 2006, the CO_2 produced in generating power to run US data centers represented roughly 16% of that produced by burning jet fuel. In 2008, data centers in the US were responsible for about 3% of the country's energy consumption, with peak load capacity projected to double roughly every 5 years and requiring 10 additional 500MW power plants between 2006 and 2011 alone [5, 2].

homes and offices through peer-to-peer (P2P) architectures. For example, a market-based P2P backup system has been proposed [5], where users trade some of their resources (storage space and bandwidth) in exchange for reliable, replicated backup. Moving backup from data centers to P2P systems leverages the free disk space already owned by users and avoids energy costs for building, running and cooling data centers. Each resource is associated with a price in units of a virtual currency, and each user makes a tradeoff about what ratio of bandwidth and disk space to supply in return for the ability to use some capacity of the backup service. Efficient power management within data centers is also important and can be enabled through expressive markets. Lubin et al. [2] have examined the use of a novel market mechanism for use within a data center for finding the right balance between power and performance. A concise and scalable language allows tradeoffs between power-performance-value to be expressed, which are then combined with models of supply and demand in order to enable the use of optimization in determining power levels and the allocation of data center resources to different customer applications.

There are many engineering challenges in developing so-called *smart markets* [4, 3]. Smart markets combine the methods of preference elicitation, optimization and incentive design in enabling the efficient allocation of resources. One challenge, in using smart markets to coordinate a multitude of small decisions by individuals (and about the actions of things that are owned by individuals), is in making these markets simple. We already have information overload, and should avoid a new wave of "decision overload" and increased cognitive cost! In addressing this problem, Seuken et al. [6] describe the challenge of *Hidden Market Design*, where one seeks to find new techniques and approaches to design and build markets for unsophisticated users. For instance, looking to design user interfaces that are simple but still able to elicit enough preference information to allow responsive supply and demand, perhaps even completely hiding some semantic concepts from users altogether (e.g., budgets or prices) [7].

A third opportunity, beyond expressiveness and market hiding, is to adopt *indirect* incentive mechanisms that operate not by eliciting preference information and solving large optimization problems— as with smart markets —but rather by perturbing the decision environments of individuals in order to *elicit useful actions* and promote better outcomes. One example of such an approach is the problem of *computational environment design* [9], which has been studied for example in finding payments to associate with observable states (e.g., the light in a room is off) in order to promote desirable behaviors. This indirect approach is related to Thaler and Sunstein's "Nudge" agenda [8], in which decision architectures are engineered to leverage behavioral biases in human decision making to perturb behaviors but without precluding any particular choice.

In summary, computational markets should find a core role in enabling computational sustainability, but will require careful, multi-disciplinary research for their promise to bear fruit.

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