and its sources can be classified on the basis of the $\delta^{13}C$ values of the major *n*-alkanoic acids, palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acid, which allows nonruminant and ruminant carcass and ruminant dairy fats to be distinguished (*21*, *22*). Ruminant dairying developed relatively quickly after the domestication of cattle, sheep, and goats (*23*); direct identification of mares' milk in pottery vessels would be clear evidence of horse domestication. Sampling of modern animal fats, including equine adipose and milk fats from Kazakh animals fed on the natural steppe vegetation, was undertaken. Although horse adipose and milk fats were resolved from the fats of ruminant animals, their $\delta^{13}C$ values overlap (Fig. 3A); hence, although equine fats can be detected with this approach, equine milk cannot be unambiguously identified.

To achieve separation, we used compound-specific deuterium isotope (δD) analysis of the major *n*-alkanoic acids, exploiting the phenomenon that in midcontinental regions, such as the Eurasian steppe, the δD values of summer and winter precipitation consistently differ by >100 per mil (*24*). Tissue lipid integrates both the water and dietary deuterium signal (*25*), hence their adipose fat integrates the annual δD signal. However, summer milk fat records only the summer δD signal; thus, the δD values of fatty acids in summer milk and adipose fats will differ because of the large difference in the δD values of summer versus mean annual precipitation. Figure 3B confirms that the δD values of the modern reference horse fats exhibit the predicted difference between adipose and summer milk fats.

The $\delta^{13}C$ values from the major fatty acid components of the Botai cooking vessels confirm the preponderance of horse fat residues (Fig. 3C), mirroring the dominance of horse bones at the site. A few residues fall into the ruminant reference distribution, which may well indicate the presence of small numbers of hunted cervids or bovids. Most significantly, the δD values show two distinct clusters. The red points in Fig. 3, C and D, correspond to the respective $\delta^{13}C$ and δD values of the same five potsherds. All the δD values of the fatty acid components of these residues exhibit significantly elevated δD values. They very likely derive from mare's milk because of their relative displacement from the major cluster of carcass fats (Fig. 3D and SOM). The relatively higher δD values in the archaeological fats are consistent with increased aridity during this period of prehistory (*26*, *27*).

Although existing archaeological evidence for horse domestication at Botai is inconclusive (*10*), our new skeletal evidence, based on metacarpal metrics, supports the presence of a proportion of domesticated horses in the Botai herds. Moreover, our bitting damage evidence indicates the use of bridles to control working animals and supports assertions that finds of leather thong–producing tools are consistent with horse domestication (*6*, *7*). Finally, evidence for extensive horse carcass product processing in pottery vessels provides direct evidence for their exploitation as a dietary staple. The demonstration of mares' milk processing confirms that at least some of the mares at Botai were domesticated. The fact that horse milking existed in a region remote from the locus of ruminant domestication in the "Fertile Crescent" and in an area seemingly devoid of domestic ruminants indicates that the evolution of strategies for exploiting animals for their milk was not contingent on the adoption of the conventional "agricultural package," as it appears to have developed independently in the Botai region.

References and Notes

1. D. W. Anthony, *The Horse, the Wheel, and Language* (Princeton Univ. Press, Princeton, NJ, 2007).
2. J. P. Mallory, *In Search of the Indo-Europeans: Language, Archaeology and Myth* (Thames and Hudson, London, 1996).
3. S. Piggott, *Wagon, Chariot and Carriage* (Thames & Hudson, London, 1992).
4. T. Jansen *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **99**, 10905 (2002).
5. C. Vilà *et al.*, *Science* **291**, 474 (2001).
6. S. L. Olsen, in *Horses and Humans: The Evolution of Human-Equine Relationships*, S. L. Olsen, S. Grant, A. M. Choyke, L. Bartosiewicz, Eds. (Archaeopress, Oxford, 2006), pp. 81–113.
7. S. L. Olsen, in *Documenting Domestication*, M. A.Zeder, D .G. Bradley, E. Emshwiller, B. D. Smith, Eds. (Univ. of California Press, Berkeley, CA, 2006), pp. 245–269.
8. M. Levine, in *Late Prehistoric Exploitation of the Eurasian Steppe*, M. Levine, Y. Rassamakin, A. Kislenko, N. Tatarintseva, Eds. (McDonald Institute, Cambridge, 1999), pp. 5–58.
9. S. Olsen, B. Bradley, D. Maki, A. Outram, in *Beyond the Steppe and the Sown*, D. L. Peterson, L. M. Popova, A. T. Smith, Eds. (Brill, Leiden, Netherlands, 2006), pp. 89–111.
10. M. Levine, in *Prehistoric Steppe Adaptation and the Horse*, M. Levine, C. Renfrew, K. Boyle, Eds. (McDonald Institute of Archaeological Research, Cambridge, 2003), pp. 1–7.
11. V. F. Zaibert, A. Tyulevaev, A. V. Zadorozhnyj, U. Kulakov, *Tajny Drevnyej Stepi: Issledovaniya Poseleniya Botaj (2004-2006)* (Kokshetauskogo Universiteta, Kokshetau, Kazakhstan, 2007).
12. S. S. Kalieva, V. N. Logvin, *Skotovody Turgaya v Tret'em Tysyacheletii do Nashej Ehry* (Kustanajckij Gosudarstvennyj Universitet, Kustanaj, Kazakhstan, 1997).
13. V. V. Yevdokimov, V. V. Varfolomeev, *Ehpoxa Bronzy Central'nogo i Cevernogo Kazaxstana* (Karagandinskij Gosudarstvennyj Universitet, Karaganda, Kazakhstan, 2002).
14. V. Eisenmann, in *Equids in the Ancient World*, R. H. Meadow, H.-P. Uerpmann, Eds. (Dr. Ludwig Reichert Verlag, Wiesbaden, Germany, 1986), pp. 67–116.
15. A. S. Gilbert, in *Equids in the Ancient World, Volume II*, R. H. Meadow, H.-P. Uerpmann, Eds. (Dr. Ludwig Reichert Verlag, Wiesbaden, Germany, 1991), pp. 75–122.
16. I. V. Foronova, in *Equids in Time and Space*, M. Mashkour, Ed. (Oxbow Books, Oxford, 2006,) pp. 20–30.
17. I. E. Grebnev, S. K. Vasil'ev, in *Steregushchie Zoloto Grify (Ak-Alakhinskie Kurgany)*, N. V. Polos'mak, Ed. (Nauka, Novosibirsk, Russia, 1994), pp. 106–111.
18. R. Bendrey, *J. Archaeol. Sci.* **34**, 1036 (2007).
19. D. G. Bennett, in *Equine Dentistry*, G. J. Baker, J. Easley, Eds. (Elsevier Saunders, London, 2005), pp. 9–22.
20. R. P. Evershed *et al.*, *Acc. Chem. Res.* **35**, 660 (2002).
21. S. N. Dudd, R. P. Evershed, *Science* **282**, 1478 (1998).
22. M. S. Copley *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **100**, 1524 (2003).
23. R. P. Evershed *et al.*, *Nature* **455**, 528 (2008).
24. K. Rozanski, L. Araguas-Araguas, R. Gonfiantini, in *Climate Change in Continental Records*, P. K. Swart, K. C. Lohmann, J. McKenzie, S. Savin, Eds. (American Geophysical Union, Washington, DC, 1993), pp. 1–36.
25. K. A. Hobson, L. Atwell, L. I. Wassenar, *Proc. Natl. Acad. Sci. U.S.A.* **96**, 8003 (1999).
26. C. V. Kremenetski, P. E. Tarasov, A. E. Cherkinsky, *Quat. Int.* **41-42**, 125 (1997).
27. P. E. Tarasov, D. Jolly, J. O. Kaplan, *Palaeogeog. Palaeocl.* **136**, 281 (1997).

28. Thanks to E. Usmanova, V. Varfolomeev, V. Loman, V. Logvin, S. Kalieva, L. Gayduchenko, D. Chivall, R. Berstan, B. Bradley, S. Babich, and E. Isayev. We are grateful for the following grants: Natural Environment Research Council grant NE/B504506/1, British Academy grant SG-35540, and NSF grants BS9816476 and BCS0415441.

Supporting Online Material

www.sciencemag.org/cgi/content/full/323/5919/1332/DC1
SOM Text
Table S1
References

17 November 2008; accepted 14 January 2009
10.1126/science.1168594

Promoting Intellectual Discovery: Patents Versus Markets

Debrah Meloso,[1]* Jernej Copic,[2] Peter Bossaerts[3]

Because they provide exclusive property rights, patents are generally considered to be an effective way to promote intellectual discovery. Here, we propose a different compensation scheme, in which everyone holds shares in the components of potential discoveries and can trade those shares in an anonymous market. In it, incentives to invent are indirect, through changes in share prices. In a series of experiments, we used the knapsack problem (in which participants have to determine the most valuable subset of objects that can fit in a knapsack of fixed volume) as a typical representation of intellectual discovery problems. We found that our "markets system" performed better than the patent system.

In a patenting system, the first to discover the solution to a problem receives a prize in the form of exclusive property rights to the fruits from the discovery. Patents are generally viewed as a superior way to promote intellectual discovery because they provide strong incentives to invest in effort, the cost of which can be recuperated from the earnings generated by applications of the discovery.

The patent system has been criticized on various grounds. First, there is the obvious fairness issue: Only the winner is compensated for effort. Second, ownership may become fragmented, which inhibits further discovery if such requires input from and coordination between the owners of prior inventions (*1*). Third, intellectual-property rights defy precise definition, and hence their scope will be subject to constant costly challenge (*2*). Lastly, patents imply monopoly rights and exploitation of monopoly rights leads to suboptimal production, sometimes no production whatsoever (*3*); the distortion becomes even more pronounced when the monopoly right covers downstream licensing (*4*).

Here, we propose an alternative, markets-based system to organize compensation of intellectual discovery. The key feature is to introduce markets for all the items that can potentially become crucial components of or inputs to implementations of a future discovery. Everyone can then own shares (securities) of these items, and these shares can be traded in an anonymous market before discovery. This way, agents who posit that a certain item is more likely to be part of a new discovery are induced to invest in it, while selling shares in items that show less potential. Incentives are indirect: Discoverers are compensated when they are the first to realize which items can solve an outstanding problem; compensation is in the form of share price increases; indeed, one can expect the value of items in useful discoveries to increase, whereas items not part of them will become cheaper. Inventors also have a strong incentive to reveal their discovery: in order for share prices to adjust in their favor as soon as possible. This should speed up development of applications based on new discoveries.

For example, concrete is made of several elements, such as gypsum, lime, water, etc. The Romans realized at one point that the addition of volcanic ash made concrete far more durable and waterproof (*5*). In a patent system, the person who first discovers (and files a patent) to add volcanic ash to concrete would be given monopoly rights to sell ash-based concrete. In the proposed markets-based system, all agents who discover that volcanic ash was a useful additive to concrete could take positions in shares whose value would increase with the price of volcanic ash. After announcement of the discovery (which the inventors would rush to make), the demand for volcanic ash would increase as use of the new additive becomes widespread, and hence the price of volcanic ash increases. The inventors are compensated indirectly for their discovery, through an increase in the value of their shareholding.

Our proposed "markets system" shares some commonalities with the "cost book system" in 19th century Cornwall that led to major advances in steam technology despite an absence of patent right filings. Key to the success of this historical system was the ability of "adventurers" (investors) to freely take positions in and trade shares of several mines, each experimenting with different technologies. Historians (*6*) have described how the cost book system not only channeled much-needed money to the most promising ideas but also fueled a period of extraordinary technological advance that was in sharp contrast with the decades before, when high royalties resulting from Watt and Boulton's patent stifled innovation. Adventurers bet directly on possible solutions (technologies). We instead propose that inventors trade claims in potential components of the best solution.

In a series of experiments, we compared the performance of a patentlike prize system against that of the proposed markets system. We used the knapsack problem (KP) as a typical representation of intellectual discovery problems. In the KP, the

[1]Bocconi University, 20136 Milan, Italy. [2]University of California Los Angeles, Los Angeles, CA 90095, USA. [3]California Institute of Technology (Caltech), Pasadena, CA 91125, USA, and Ecole Polytechnique Fédérale Lausanne, 1015 Lausanne, Switzerland.

*To whom correspondence should be addressed. E-mail: debrah.meloso@unibocconi.it

A

Weight limit: 1500

	A	B	C	D	E	F	G	H	I	J
Values	37	72	106	32	45	71	23	44	85	62
Weights	50	820	700	46	220	530	107	180	435	360
Solution										

B

C

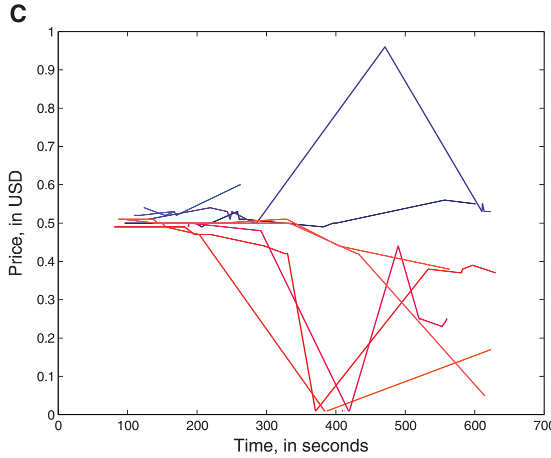


Fig. 1. (**A**) Presentation of an instance of the KP (instance IV), as seen by experiment participants. The first row lists the values of the items and the second one, their weights; the third row is left blank for participants to enter their suggested solution. The weight limit of the container is indicated on top of the table. The goal is to find the combination of the items that maximizes total value and is feasible (i.e., fits within the weight limit of the container). Objects are indivisible. (**B**) Snapshot of a typical trading interface in the markets treatment. Each column on the left-hand side provides price levels at which orders to buy (indicated in blue) and orders to sell (in red) can be entered. Orders are entered by a simple click of the mouse. Trades take place automatically when an order to buy is entered at a price above the best available sell order or when an order to sell is entered at a price below the best available buy order. Participants can see their current holdings above the columns. A list of the participant's current standing orders is provided to the right; above it is a chart with past transaction prices; below it is a summary of earnings in past trading rounds. (**C**) Evolution of transaction prices during a typical experimental period. Lines in blue connect trade prices for each of the securities that represent positions in in items (items that are part of the optimal solution); lines in red connect trade prices of securities corresponding to out items. Although initially equal, trade prices of in securities tend to increase, whereas those of out securities tend to decrease. USD indicates U.S. dollars.

challenge is to find the optimal combination of a number of components (items). Specifically (Fig. 1A), participants were asked to fill containers with at most 10 to 12 items; containers had a weight constraint, which meant that generally not all items fit; items had different values; the goal was to maximize total value of items that could fit.

At the heart of the KP is the task to devise the right combination of a potentially large number of inputs. In the economics literature (*7*, *8*), intellectual discovery is generally modeled as an exercise of information aggregation, in which all disparate pieces of information (signals) need to be merely added. The KP is different from information aggregation because it involves deciding which inputs to combine. This is a computationally far more demanding exercise (*9*). For instance, one can never be sure whether an item is in the optimal solution until one derives the entire optimal solution. We claim that the KP better reflects intellectual discovery because it too requires one to put things together in original ways rather than just adding things up. To quote (*4*), "Two half-baked ideas do not equal one fully-baked idea."

In our experiment, we used eight instances (variations) of the KP. The instances varied in degree of difficulty, as measured by an index based on Sahni's heuristics (*10*, *11*). This would enable us to determine whether the success of a particular system was uniform or applied only to a limited range of problems. In our prize system, we rewarded the first participant to discover the optimal solution with $66 (all values are given in U.S. dollars). Although we imposed a time constraint (420 s), it was binding in only one instance (no one found the right solution within the allowed time). To best reflect real-world patent systems, discovery was immediately and publicly announced. However, the nature of the solution was not revealed, and participants could continue work on the KP instance at hand. After time elapsed, participants handed in their suggested solutions. However, only the person who first discovered the right solution was compensated.

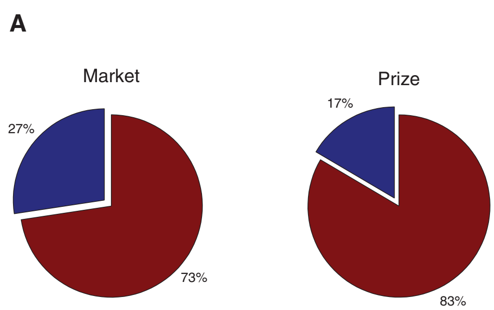
In the markets system, participants were given an equal number of shares in each of the items of the particular KP, as well as cash. They could trade these shares in an anonymous, electronic exchange platform during a preset amount of time (840 s). The allowed time was double that of the prize system to compensate for the fact that subjects needed to perform two tasks: to solve the KP and to trade (to exploit the knowledge they gained from solving the KP). The platform was organized as a continuous double-sided open book (Fig. 1B), like most purely electronic stock markets in the world. The accumulation of orders generated the first transactions after about 100 s. Thereafter, trading remained brisk in virtually all markets (Fig. 1C). After markets closed, each share in an item that was in the optimal solution paid a liquidating dividend of $1; shares corresponding to items not in the optimal solution expired worthless.

In the markets system, we arranged initial allocations such that we paid on average a total of $60 to $68 in dividends per instance, depending on the number of participants. These numbers were deliberately made as close as possible to the amount we paid to the single participant who discovered the right solution in the prize system ($66) to ensure that incentives were strictly less in the markets system. In the markets system, the total payments were distributed across participants depending on the number of shares of each item they were holding at the close of the markets. As such, a participant who knew the optimal solution could only obtain the same compensation as in the prize system if she or he were able to buy all shares for items in the solution with the proceeds from selling her or his remaining shares, a highly unlikely situation. We also collected participants' suggested solutions after markets closed; we did not compensate for correctness of these suggestions to avoid introducing prizelike features.

In each experiment, participants solved four instances of the KP under the prize system and four instances under the markets system. We repeated the experiment four times, so that each instance was solved twice under both systems. In one session, there were 17 participants; in all other, 15 participants. The experiments had the approval of the Caltech Institute Review Board for the protection of human participants.

The correct solution was found under the markets system whenever this was the case under the prize system. Therefore, if the concern is to design a system that produces the optimal solution, the markets and prize systems are equivalent. In one important respect, however, the markets system outperformed: Significantly more participants reported the correct solution than under the prize system (Fig. 2A). For both systems, the fraction of participants who reported the correct solution declined with problem difficulty (Fig. 2B). The fraction may seem to decline faster for the markets treatment, but the difference in slopes was not significant. An outlier influenced the fits: Nobody ever solved the most difficult problem (difficulty = 6). It was solved in follow-up experiments [ran to check for robustness (*11*)], but only with the markets system, further corroborating its superiority.

In the prize system, only the first to find the optimal solution is compensated, which may discourage many from spending effort. In the markets system, everyone could be compensated in principle, which may be sufficient to explain why more participants find the optimal solution. Alternatively, prices may convey information that facilitates problem solving for participants who would never find the optimal knapsack on their own. Figure 3A shows that prices indeed do provide a potential channel of communication: Prices of shares of items that were part of the optimal knapsack ("in" items) tended to be higher than shares of items that were not part of it ("out" items); the mean transaction price of in items was significantly higher than that of out items ($P < 0.01$). Figures S1 to S8 show how prices of the in and out items diverge over time. It would have been interesting to explore the impact of this divergence on the ability and



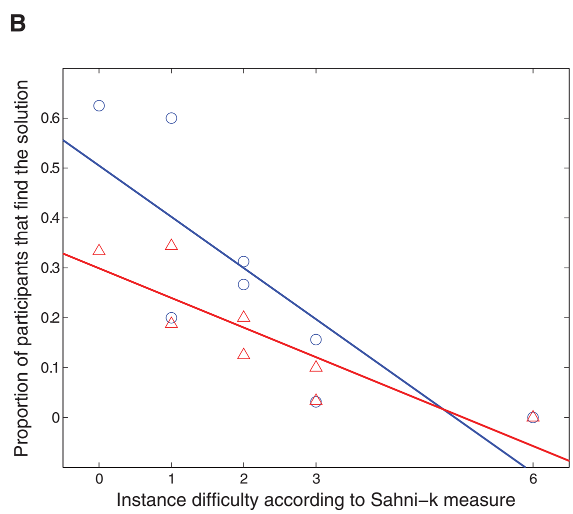


Fig. 2. (**A**) Overall proportion of participants that reported the correct solution (blue) and the incorrect one (red) for the markets and the prize treatments. The proportions are significantly different across treatments (χ^2 statistic of equality of two binomial distributions = 6.28; $P = 0.01$). (**B**) Proportion of participants who reported the correct solution of each instance of KP as a function of the difficulty of the problem. Blue circles indicate the markets treatment; red triangles represent the prize treatment. Least-squares fits for the markets (blue line; $R^2 = 0.64$) and price treatments (red line; $R^2 = 0.74$) are shown. Slopes of the two lines are significant ($P = 0.01$ and $P < 0.01$, respectively).

speed with which participants discover the optimal solution. However, this would have required us to introduce incentives for participants to submit suggested solutions every minute or so. The resulting side payments would have blurred the comparison with the prize system.

In the markets system, subjects are compensated indirectly for superior problem solving skills: Those who figure out the right solution buy "in" securities and sell "out" securities, to eventually be paid higher total dividends. As a result, we expect to find more divergence in final holdings of shares than in initial holdings. Because we started all participants with equal number of shares in each of the items (namely, five), any dispersion in final holdings would be consistent with this expectation. Final holdings for both in and out securities displayed substantial dispersion (Fig. 3B). Final holdings of out are more frequently below initial holdings than those of in. Because total frequencies have to add up to 100%, the higher frequencies of low final holdings of out needed to be offset somehow. Figure 3B shows that the offset came from (i) lower frequency of final holdings equal to initial endowments and (ii) higher frequencies of extremely high final holdings (the percentage outcomes for out beyond 15 was almost four times larger than for in: 1.66% against 0.43%; the maximum for out holdings, at 37 units, was substantially above that for in holdings, at 28).

Despite the absence of direct incentives, the experimental results indicate that our markets system performs better than a patentlike prize system. Referring to the five criticisms of the patent system, (i) our market system is fairer in the sense that anyone who finds the optimal solution can potentially win by taking the right positions in the markets; (ii) it does not lead to fragmented ownership of intellectual property rights because the optimal solution is in the public domain; (iii) defining the scope of intellectual property rights is not a problem because they do not exist in the first place; (iv) no monopoly rights result from finding the optimal solution; and likewise (v) downstream licensing is not needed: anyone can use the optimal solution without having to directly compensate the discoverer.

It may be argued that more people in the market system discovering the same (solution) is inefficient. What ultimately counts, however, is total cost to obtain the discovery, which in our experiments was identical across the two systems. In addition, repeated discovery should be beneficial in situations where there is a discovery learning curve (i.e., when successful future discovery depends critically on full experience with the process that led to past discoveries).

The patent system has been motivated by the fact that the information embedded in a discovery is a nonexcludable and nonrival good. Economic theory argues that markets for such goods will fail (*8*). Our data suggest that this claim is false. The results underscore the necessity of experimentation when deciding between public institutions.

In certain cases, real-world implementation of our markets system already exists. Take, for instance, fuel cell technology. Successful development of this technology will depend, among others, on finding the right catalyst. This is putting tremendous pressure on prices of all catalysts, starting with platinum. Markets in platinum exist already. Those who think that platinum will provide the best catalyst will profit, if their belief is right, from buying platinum shares. New markets in competing catalysts, such as carbon silk, are bound to emerge. Positions in the various markets implement bets on different fuel cell technologies. These positions could go both ways: If an inventor thinks platinum is not the

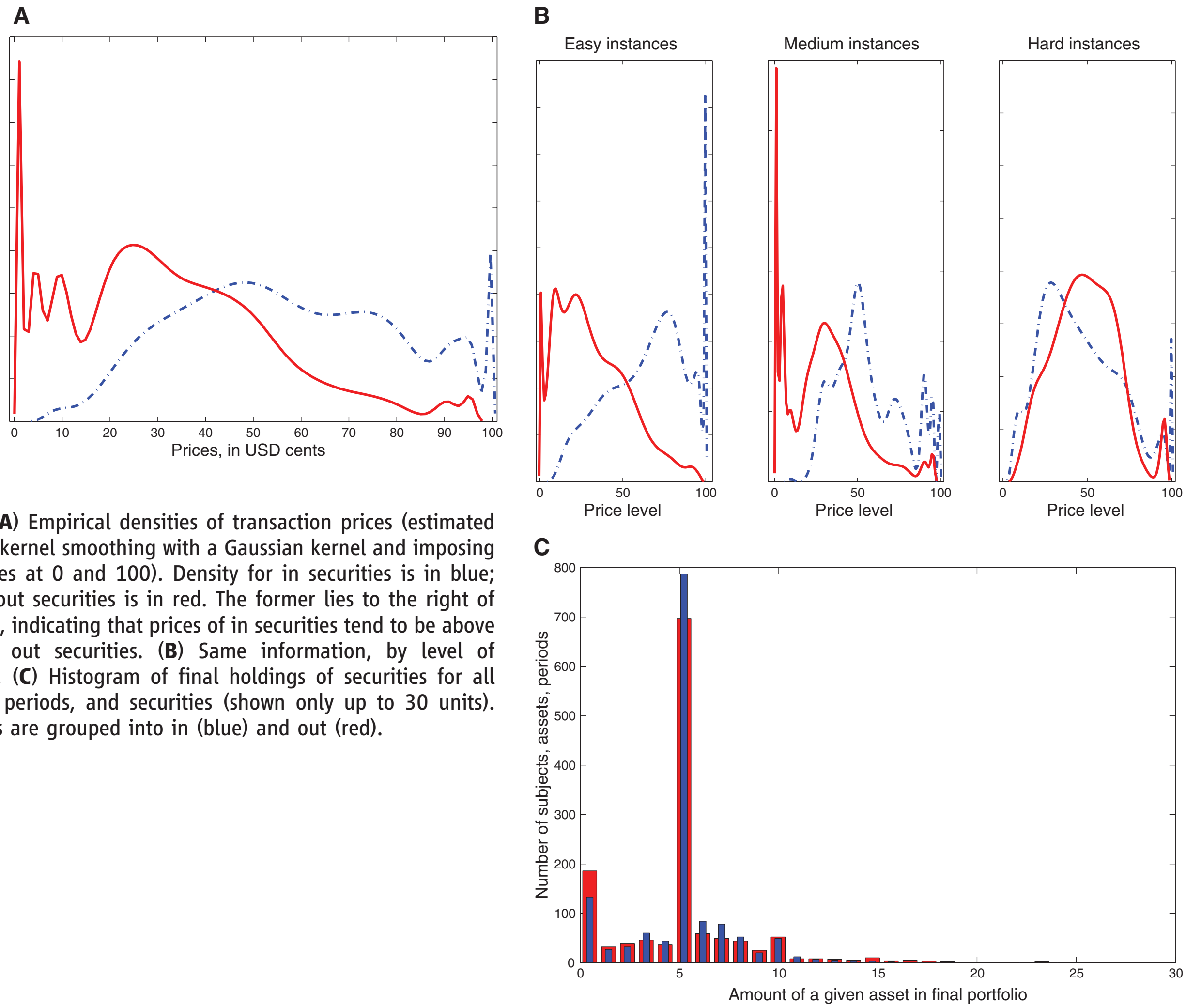


Fig. 3. (**A**) Empirical densities of transaction prices (estimated by using kernel smoothing with a Gaussian kernel and imposing boundaries at 0 and 100). Density for in securities is in blue; that for out securities is in red. The former lies to the right of the latter, indicating that prices of in securities tend to be above those of out securities. (**B**) Same information, by level of difficulty. (**C**) Histogram of final holdings of securities for all subjects, periods, and securities (shown only up to 30 units). Securities are grouped into in (blue) and out (red).

answer, then she or he could short-sell this metal to profit from the expected reduction of the platinum price. Of course, the prices of catalysts are affected not only by advances in fuel cell technology but also by usage for other purposes. Still, financial engineers nowadays are capable of tailoring positions to isolate one specific source of risk. The fuel cell example illustrates how inventors at present may actually be able to profit from a discovery twice: through the monopoly granted by the patent and through positions in markets for catalysts. We propose to eliminate the former, leaving inventors only with the incentives provided by the latter. Our experiments show that this is sufficient to promote intellectual discovery.

In our experiments, subjects were paid as a function of the very best solution. We consider this to be an idealized situation afforded by the experimental setting, which allows for a clear interpretation of performance numbers. In practice, inventors will be compensated for second-best solutions as long as the best one has not been attained yet. This is precisely what happened in 19th century Cornwall: Engineers never really found the best way of building steam engines (we know this because many improvements were made afterward), but they were rewarded for providing better solutions.

The traditional patent system helps people with an idea even if they have no resources, because those who have the resources (usually venture capitalists) provide inventors with cash in return for a share in the intellectual property rights. In our markets system, resources would be generated in a similar way. The people with the ideas but no money could approach investors (such as fund managers) and inform them. These investors could then take positions to exploit expected changes in valuations from adoption of the new technology. They should be eager to pay for the information, and this payment will provide the inventors with the necessary cash for development.

We do not claim that our markets system will work under all circumstances. We envisage that it could replace the patent system whenever a technology builds on goods and services with economic rents, which means that their cost of provision is below market value. Such rents obtain for a variety of reasons. One is limited supply (volcanic ash in the concrete example, platinum in the fuel-cell case, artemisinin in the case of medication against drug-resistant malaria, or the claims to the items in the knapsacks in our experiments). Other important reasons are first-mover advantage (this seems to have been the case with steam engine technology in the mines of Cornwall in the mid-19th century) and lead in the learning curve [studied extensively in the economics literature; see (*7*)].

The success of our markets system relies on willingness to trade; without trading, those who make progress toward finding the optimal solution cannot exploit their acquired knowledge. In our setting, participants never know whether they have the optimal solution (because they would need much more time to check all possible solutions). Thus, there is always the possibility that one is trading with a counterparty who knows better. Why, then, would participants trade? We conjecture that they trade because they tend to be too confident that they are closer to solving the problem than others. Overconfidence is indeed an important human trait, best illustrated by the fact that more than 50% of people usually think they are better than the median (*12*). Other, nonpecuniary incentives for trade (such as a taste for being "right") may play a role. Further research is needed to identify the origin of the success of the markets system in promoting intellectual discovery.

Our proposal relies on anonymous, two-way markets. Until recently, setting up new markets required time. Modern technology, however, has enabled quick design, ready deployment, and low-cost management of markets. With the open-source software we developed for our experiments, jMarkets (*13*), setting up and launching of (online) markets can be done in a matter of hours.

Our experimental findings suggest that the patent system is not a universally superior way to incentivize intellectual discovery. We propose a markets-based system that we found to work better. Its main features are that the compensation for inventions is shared and that, because discovery remains in the public domain, it avoids both distortion in the provision of newly invented products and stifling of future discovery.

References and Notes

1. M. A. Heller, R. S. Eisenberg, *Science* **280**, 698 (1998).
2. A. B. Jaffe, *Res. Policy* **29**, 531 (2000).
3. R. J. Gilbert, D. M. G. Newbery, *Am. Econ. Rev.* **72**, 514 (1982).
4. M. Boldrin, D. Levine, *Am. Econ. Rev.* **92**, 209 (2002).
5. R. Siddall, *Geol. Soc. London Spec. Publ.* **171**, 339 (2000).
6. A. Nuvolari, *Camb. J. Econ.* **28**, 347 (2004).
7. K. Arrow, *Rev. Econ. Stud.* **29**, 155 (1962).
8. N. Gallini, S. Scotchmer, in *Innovation Policy and the Economy*, A. Jaffe, J. Lerner, S. Stern, Eds. (MIT Press, Cambridge, MA, 2002), vol. 2, pp. 51–78.
9. H. Kellerer, U. Pferschy, D. Pisinger, *Knapsack Problems* (Springer-Verlag, Heidelberg, 2004).
10. S. Sahni, *J. Assoc. Comput. Mach.* **22**, 115 (1975).
11. Materials and methods are available as supporting material on *Science* Online.
12. B. Biais, D. Hilton, K. Mazurier, S. Pouget, *Rev. Econ. Stud.* **72**, 287 (2005).
13. http://jmarkets.ssel.caltech.edu.

14. This study was partly funded by the U.S. NSF (grants SES-0616431 and SES-0317715) and the Swiss Finance Institute.

Supporting Online Material

www.sciencemag.org/cgi/content/full/323/5919/1335/DC1
Materials and Methods
SOM Text
Figs. S1 to S11
Tables S1 to S5
References

3 April 2008; accepted 5 January 2009
10.1126/science.1158624

Molecular and Evolutionary History of Melanism in North American Gray Wolves

Tovi M. Anderson,[1] Bridgett M. vonHoldt,[2] Sophie I. Candille,[1] Marco Musiani,[3] Claudia Greco,[4] Daniel R. Stahler,[2,5] Douglas W. Smith,[5] Badri Padhukasahasram,[6] Ettore Randi,[4] Jennifer A. Leonard,[7] Carlos D. Bustamante,[6] Elaine A. Ostrander,[8] Hua Tang,[1] Robert K. Wayne,[2] Gregory S. Barsh[1]*

Morphological diversity within closely related species is an essential aspect of evolution and adaptation. Mutations in the *Melanocortin 1 receptor* (*Mc1r*) gene contribute to pigmentary diversity in natural populations of fish, birds, and many mammals. However, melanism in the gray wolf, *Canis lupus*, is caused by a different melanocortin pathway component, the *K* locus, that encodes a beta-defensin protein that acts as an alternative ligand for Mc1r. We show that the melanistic *K* locus mutation in North American wolves derives from past hybridization with domestic dogs, has risen to high frequency in forested habitats, and exhibits a molecular signature of positive selection. The same mutation also causes melanism in the coyote, *Canis latrans*, and in Italian gray wolves, and hence our results demonstrate how traits selected in domesticated species can influence the morphological diversity of their wild relatives.

The correspondence between coat color and habitat is often attributed to natural selection, but rarely is supporting evidence provided at the molecular level. In North American gray wolves, coat color frequencies differ between wolves of forested and open habitats throughout western North America (*1*), including Denali National Park (*2*) and the Kenai Peninsula in Alaska (*3*), and much of the Canadian Arctic (*4*, *5*). These differences are especially dramatic between wolves of the high tundra that are migratory and follow barren-ground caribou to their breeding areas, and wolves that are year-round residents in the neighboring boreal forest and hunt nonmigratory prey.