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Morals and Markets

Armin Falk[1]*† and Nora Szech[2]*†

The possibility that market interaction may erode moral values is a long-standing, but controversial, hypothesis in the social sciences, ethics, and philosophy. To date, empirical evidence on decay of moral values through market interaction has been scarce. We present controlled experimental evidence on how market interaction changes how human subjects value harm and damage done to third parties. In the experiment, subjects decide between either saving the life of a mouse or receiving money. We compare individual decisions to those made in a bilateral and a multilateral market. In both markets, the willingness to kill the mouse is substantially higher than in individual decisions. Furthermore, in the multilateral market, prices for life deteriorate tremendously. In contrast, for morally neutral consumption choices, differences between institutions are small.

It is a pervasive feature of market interaction to impose costs on uninvolved third parties. Producing and trading goods often creates negative externalities, such as detrimental working conditions for workers, possibly associated with reduced life expectancy, child labor, suffering of animals, or environmental damage. People who participate in markets by buying such goods often seem to act against their own moral standards. The risk of moral decay through market interaction has been discussed in politics, ethics, and in the social sciences (*1*–*7*). Observing that with technological progress and the increasing ubiquity of market ideas, markets continue to enter further and further into domains of our social life (*8*), political philosopher Michael Sandel has recently reemphasized this critique, stating that "we have to ask where markets belong—and where they don't. And we can't answer this question without deliberating about the meaning and purpose of goods, and the values that should govern them" (*9*). The relationship between markets and values has received attention both in theoretical work (*10*, *11*) and in empirical cross-sectional studies that compare the level of prosociality across different market societies and cultures (*12*–*14*). Identifying a causal effect of markets on values is difficult with cross-sectional or historical data, however, simply because institutions and values coevolve. Moreover, comparing values across societies implies comparing a set of multiple institutions at the same time with unknown and possibly interacting features. For example, markets are observed in very different legal systems, which renders the isolation of the effects of "markets" across societies extremely difficult. For these reasons, we implemented a controlled environment by randomly assigning subjects to different institutions. This allows identifying a causal effect of institutions on outcomes. Our evidence shows that market interaction causally affects the willingness to accept severe, negative consequences for a third party.

The Mouse Paradigm

Our paradigm for studying moral values and detrimental effects on third parties is the trade-off between a mouse life and money. In our main treatments, human subjects faced the decision to either receive no money and to save the life of a mouse, or to earn money and to accept the killing of a mouse. This paradigm involves a drastic and irreversible decision and is well suited for studying moral conflict: Although the content of morality is culturally determined and time and space contingent, there exists a basic consensus that harming others in an unjustified and intentional way is considered as immoral (*15*).

In all treatments of the experiment (*16*), which was approved by the Ethics Committee of the University of Bonn, subjects were explicitly informed about the consequences of their decision. They knew that their mouse was a young and healthy mouse, which in case it survived would in expectation live for about 2 years in an appropriate, enriched environment, jointly with a few other mice. For illustrative purposes, we presented to subjects the picture of a mouse on an instruction screen (fig. S1). The instructions informed subjects explicitly about the killing process, in case they decided to kill their mouse. The killing process was also shown in a short video that was presented to subjects (*17*).

The mice used in the experiment were so-called "surplus" mice: They were bred for animal experiments, but turned out to be unsuited for study, e.g., because some specific gene manipulation had failed. They were perfectly healthy, but keeping them alive would have been costly. Although it was true that the mice would live or be killed based on the decisions of subjects in the experiment, the default for this population of mice was to be killed, as is common practice in laboratories conducting animal experiments. Subjects were informed explicitly about the default in a postexperimental debriefing (*18*). Mice that were chosen to survive because of subjects' decisions were purchased by the experimenters and kept in an appropriate, enriched environment. Thus, these mice survived precisely as stated in the instructions. As a consequence of our experiment, many mice that would otherwise have been killed right away were allowed to live for roughly 2 years.

Markets are institutions where sellers and buyers interact and can trade items. Trade occurs whenever a seller and a buyer agree on a price. For our main result, we analyzed three different conditions (see table S1): an individual treatment in which subjects decided between the life of their mouse and a given monetary amount, a bilateral trading market, and a multilateral trading market. Treatment assignment was random. The individual treatment serves as a benchmark and comparison standard for decisions made in markets. The bilateral market is the most basic form of a market situation with one buyer and one seller bargaining over prices in order to trade. In the multilateral market, many buyers and sellers potentially trade with each other. In comparing

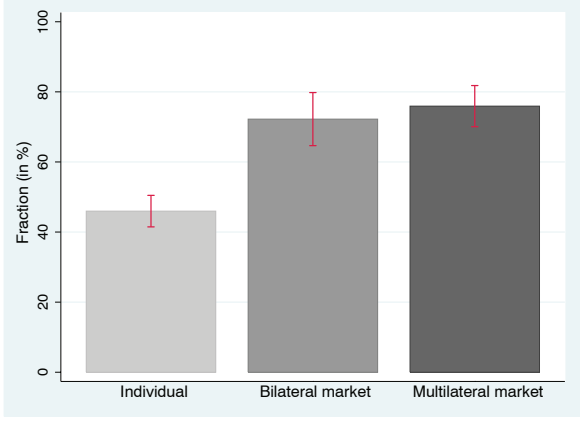

Fig. 1. Market interaction erodes moral values, relative to individually stated preferences: fractions of subjects who are willing to kill a mouse for monetary amounts below or equal to 10 euros in the individual treatment, the bilateral market, and the multilateral market. For both markets, fractions are calculated using the lowest prices accepted by sellers in actually concluded trades. Error bars show standard deviations at the means. Differences between the individual treatment and markets are significant at the 1% level. Individual versus bilateral market: $P < 0.01$, $n = 160$ (two-sample test of proportions). Individual versus multilateral market: $P < 0.01$, $n = 178$ (two-sample test of proportions). The difference between markets is not statistically significant.

[1]Center for Economics and Neuroscience, University of Bonn, Bonn, Germany. [2]Department of Economics, University of Bamberg, Bamberg, Germany.

*Both authors contributed equally to this work.
†Corresponding author. E-mail: armin.falk@uni-bonn.de (A.F.); nora.szech@uni-bamberg.de (N.S.)

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decisions from the individual treatment to decisions made in markets, we abstract away from the question of whether a good is priced at all. In all treatments, subjects could exchange life for money.

In the individual treatment, subjects faced a simple binary choice, labeled option A and option B. Option A implied that the mouse would survive and that the subject would receive no money. Option B implied the killing of the mouse and receiving 10 euros. This treatment informs us about the fraction of subjects who are willing to kill the mouse for 10 euros. One hundred and twenty-four subjects participated in this treatment.

To study markets, we implemented the so-called double auction market institution, which is widely used in economics to investigate market outcomes [for an overview, see (*19*)]. In the bilateral double auction market, one seller and one buyer bargained over killing a mouse for a total gain of 20 euros that the two parties could split up between themselves. The seller was endowed with a mouse. As in the individual treatment, he or she was explicitly told that the "life of the mouse is entrusted to your care." Bargaining over the 20 euros was conducted during a continuous auction, i.e., buyer and seller could make as many price offers as they liked (*16*). If a buyer and a seller agreed on a trade, the buyer received 20 euros minus the price agreed upon. The seller received the price. In addition, the mouse of the seller was killed, reflecting a situation in which trade takes place to the detriment of a third party. If a seller or a buyer did not trade, earnings for both were zero and the mouse survived. A seller in the bilateral market was in the same situation as a subject in the individual treatment in that he or she could either refuse a monetary amount or accept a monetary amount and kill a mouse. Subjects were told that no market participant was forced to make price offers or to accept an offer, that their mouse would be killed only if a trade occurred, and that the mouse would survive if they decided not to trade. There were 10 trading periods. Seventy-two subjects participated in this treatment.

The multilateral double auction market treatment was exactly like the bilateral market treatment, except that in this condition seven buyers and nine sellers bargained over prices (*16*). The nine sellers were all endowed with one mouse each. Subjects on both sides of the market could make as many price offers as they liked. All subjects could accept a price offer from the other side of the market. Available price offers of both market sides were always shown on a screen. Once a price offer of a trader was accepted, trade occurred implying the killing of a mouse. Payoff consequences were identical to those of the bilateral market. There were 10 periods. We ran six sessions with a total of 96 subjects.

To allow for further analyses, we ran several additional treatments (for details see below). In the individual price-list treatment, we offered subjects a menu of prices to elicit the monetary amount needed to pay subjects to make them indifferent between killing and receiving money. To establish a benchmark in terms of how markets affect morally neutral values, we conducted an individual price-list treatment and a multilateral market treatment analogously to the mouse treatments, but for a consumption good. Finally, we ran two further control treatments based on the individual treatment. In sum, we ran nine treatments with a total of 787 subjects.

Our key hypothesis was that markets would display a tendency to erode moral standards, relative to individual decision-making, because of three essential features of market interaction. First, in markets, it takes two people who agree on trading to complete a trade, implying that responsibility and feelings of guilt may be shared and thus diminished (*20*, *21*). Second, market interaction reveals social information about prevailing norms. Observing others trading and ignoring moral standards may make the pursuit of self-interest ethically permissible, leading further individuals to engage in trade. In addition, the mere existence of a market may provide social information about the appropriateness of trading, rendering the killing of mice more allowable (*22*, *23*). Third, markets provide a strong framing and focus on materialistic aspects such as bargaining, negotiation, and competition, and may divert attention from possible adverse consequences and moral implications of trading (*11*, *24*). In contrast to our market conditions, subjects in the individual condition do not interact with other subjects and therefore receive no social information, do not share responsibility if they trade, and are not exposed to a market framing.

These three features are present in all markets, even in simple bilateral markets. In addition, in the multilateral market with its presence of competing sellers, the notion of being pivotal may be diffused as well (*25*); unless a seller cares specifically about his own mouse, he may argue that if he does not trade his mouse with some buyer, another seller may conclude the trade with that buyer, selling and killing his mouse. This common feature of markets may make subjects feel less responsible, rendering it more difficult to sustain moral values even if values per se remain unchanged. In sum, we therefore expected a higher willingness to kill in the bilateral and the multilateral market compared to individual decision-making. In addition, owing to notions of being less pivotal, the killing rate was expected to be even higher in the multilateral than in the bilateral market. We further hypothesized that the decay of moral values would also be reflected in prices, such that mice would be killed for lower prices in the market treatments compared to the individual treatments. Finally, we studied markets where the cost of trading involves opportunity costs of consumption rather than moral costs. For these morally neutral consumption good markets, we hypothesized no decline of values through market interaction.

Markets Erode Moral Values

Figure 1 shows our main result. Given our interest in studying the effects of institutions on moral valuations in a given population, we compare the fractions of subjects who are willing to agree to the killing in the individual treatment, the bilateral market, and the multilateral market for monetary amounts below or equal to 10 euros (*26*). For both markets, fractions are calculated with the lowest prices accepted by sellers in actually concluded trades. We focus on lowest accepted prices to approximate from above sellers' reservation values for killing a mouse.

In the individual decision treatment, 45.9% of subjects were willing to kill their mouse for 10 euros. In contrast, 72.2% of sellers in the bilateral market were willing to trade for prices below or equal to 10 euros. The increase in willingness to kill relative to the individual condition is statistically significant ($P < 0.01$, $n = 160$, two-sample test of proportions) (*16*). In the multilateral market, the willingness to kill was also substantially higher compared to the individual condition: 75.9% of sellers were willing to kill a mouse for less than or equal to 10 euros ($P < 0.01$, $n = 178$, two-sample test of proportions). This is actually a lower bound because in a given period, only seven of the nine sellers could trade at all.

To provide a more detailed understanding of the effects of markets on morals, we implemented

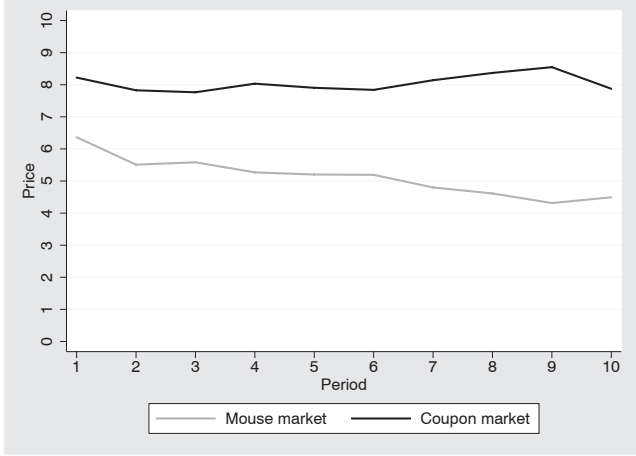

Fig. 2. Evolution of trading prices in the multilateral mouse market and the multilateral coupon market (means over all trades). The downward trend in prices in the mouse market is significant ($P = 0.006$, $n = 297$, random effects regression). No significant price trend is observed in the coupon market ($P = 0.319$, $n = 233$, random effects regression).

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an additional individual treatment, the individual price-list treatment. This treatment informs us about how much money subjects would need to receive in the individual condition to yield a similarly high killing rate as in markets. In this treatment, subjects faced an increasing price-list, which is a standard procedure for eliciting individual values and preferences in an incentive-compatible way. As in the individual treatment, subjects were shown a list of binary alternatives, labeled option A and option B. Option A implied that the mouse would survive and that the subject would receive no money. Option A was the same in each decision row. Option B implied the killing of the mouse and the receipt of a monetary amount. Monetary amounts associated with killing the mouse increased from row to row, starting from 2.50 up to 50 euros, in steps of 2.50. Subjects were informed that one choice situation would be randomly selected after all choices had been made. The choice in this situation would be implemented, including payment consequences and, in case option B had been chosen, the killing of the mouse. The switching point from option A to option B informs us about the minimum monetary amount that makes a subject willing to kill the mouse, i.e., the moral value attached to the life of the mouse. The earlier a subject switches, the less he or she values the life of his or her mouse relative to earning money. Despite differences in elicitation procedures, including randomness of the selected choice, the fractions of subjects willing to kill for 10 euros or less were almost identical between the individual and the individual price-list treatment (45.9 versus 42.7% of subjects, respectively; $P = 0.636$, $n = 220$, two-sample test of proportions) (fig. S2). Ninety-six subjects participated in the individual price-list treatment.

As shown above, in the bilateral trading market, 72.2% of sellers were willing to trade for prices below or equal to 10 euros. In comparison, in the individual price-list treatment, a similarly high willingness to kill (71.9%) was reached only for monetary amounts of 47.50 euros. Thus, it is necessary for subjects to receive considerably more money in the individual than in the market condition to observe a comparable willingness to kill. Turning to the multilateral market, a similar picture emerges. Here the killing rate was 75.9% for prices below or equal to 10 euros. A similar rate in the individual price-list treatment would require paying subjects monetary amounts above 50 euros. In line with our hypothesis, actual prices in the multilateral market were much lower than 10 euros, however (Fig. 2). The overall average price level was only 5.1 euros (*27*). In the individual price-list condition, the fraction of subjects who were willing to kill the mouse for 5 euros was only 34.4%. Thus, for prices that actually evolved in the multilateral market, the willingness to kill was much higher than in the individual price-list condition.

The price-list treatment can also be used to illustrate the decay in valuations in terms of the predicted fraction of trade (*16*). Assuming that valuations in the price-list condition and the bilateral market were the same, we can use valuations from the price list to simulate the predicted trade probability in the bilateral market. The simulated trade fraction is 25.9%, which is in sharp contrast to the actually observed trade frequency of 47.7% in the bilateral market ($P < 0.01$, $n = 168$, two-sample test of proportions). This provides a further confirmation that valuations for mice have declined considerably.

Moral Versus Morally Neutral Values

The final step of the analysis compares decay in moral versus morally neutral values. We hypothesized that for moral values the decay is more pronounced than for private consumption values, where trading involves opportunity costs of consumption rather than costs to third parties. To test this, we ran two additional treatments, identical to the multilateral market and the individual price-list treatment but using consumption goods. The good we considered was a coupon that could be used to buy products at the merchandising shop of the University of Bonn (*16*). In both treatments, the price-list and the market treatment, subjects were endowed with a coupon. In case they accepted a monetary amount (in the price-list condition) or decided to trade (in the market condition), they had to return their coupon, which was then invalidated. Parameters, instructions, and procedural details were identical to the mouse treatments. Thus, consequences were similar in the mouse and the coupon treatments, except that in the latter, the cost of trading involved opportunity costs of consumption rather than moral costs, i.e., loss and invalidation of a coupon versus killing of a mouse.

To assess the effect of markets on moral versus private consumption values, we use valuations from the individual price-list conditions and compare them to valuations in the respective multilateral markets (*16*). The dependent variable is a subject's minimum trading price. Running Tobit and interval regressions, we find that in the mouse treatments, there is a strong negative and statistically significant effect of market interaction. Thus, for a given monetary amount, subjects reveal a higher willingness to kill in markets than in the individual condition. For coupons, the effect of markets is much smaller and insignificant. We also find that the effects of markets differ significantly between mice and coupons (*16*). In addition, we observe a difference in the price dynamic between multilateral mouse and coupon markets (Fig. 2). In the mouse market, average prices start at rather low levels (compared to the individual condition) and decline from 6.4 euros in the first period to levels as low as 4.5 euros in the final period. This decline in prices is statistically significant ($P = 0.006$, $n = 297$, random fixed effects regression). The downward trend provides a further indication of moral decay in the mouse market and is suggestive of social learning and endogenous social norm formation. Intuitively, observing low trading prices in the market may make it normatively acceptable to offer or accept low prices as well (*16*). In contrast to the downward trend in prices in the mouse market, no significant price trend is observed in the coupon market ($P = 0.319$, $n = 233$, random fixed effects regression). The analysis thus reveals a systematic difference between markets involving moral versus morally neutral values: When identical procedures, parameters, and market institutions are used, moral values decline significantly more than values that are morally neutral.

Whereas prices decline in the multilateral mouse market, trade volumes in both bilateral and multilateral markets are constant across periods, suggesting that a number of subjects were not tempted to engage in trading. Apparently, markets did not erode values of all subjects (*16*). We speculate that subjects who refused to exchange money for mouse life at all may have followed a rule-based, e.g., Kantian, ethic: "… everything has either *price* or *dignity*. Whatever has price can be replaced by something else which is *equivalent*; whatever, on the other hand, is above all price, and therefore admits of no equivalent, has a dignity" (*16*, *28*).

Robustness and Discussion

Three potential concerns may be raised with respect to our main finding. First, one could argue that we observe the main treatment effect because total surplus was greater in markets than in the individual condition (20 versus 10 euros). If traders dispose of social preferences, they may have cared not only about their own payoff but also attached some value to the payoff of the other trader (buyer). We therefore ran a control condition, which was identical to the individual condition but in which we introduced a second passive participant. One hundred and sixteen subjects took part in this control treatment, with 58 subjects participating in the role of active decision-makers. A passive participant received 10 euros if the active participant decided to kill the mouse (such that the death of a mouse generated a total surplus of 20 euros as in the market treatments). The observed fraction of killing among subjects in the active role is 44.8%. This fraction is significantly different from fractions in both market conditions (bilateral market, $P = 0.009$, $n = 94$, and multilateral market, $P = 0.001$, $n = 112$, two-sample test of proportions). Furthermore, this fraction is remarkably similar to the individual condition ($P = 0.890$, $n = 182$, two-sample test of proportions).

Second, subjects may have perceived killing the mouse as a side-effect of the act of trading in the market treatments, whereas in the individual treatment subjects may have perceived killing the mouse as a direct means to earn money. If this were the case, subjects may have found it more difficult to opt for killing in the individual treatment. We therefore ran another control treatment identical to the individual treatment but in which

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subjects could buy a lottery ticket for 2 euros. This renders it more likely that subjects perceive the mouse death as a side-effect of a buying decision. The lottery paid out either 10 or 15 euros, respectively, both with 50% probability. We chose an expected net value of 12.50 – 2 = 10.50 euros to compensate for possible risk aversion of subjects. If subjects bought the lottery ticket, a mouse got killed "as another consequence" of the buying decision, i.e., as a side-effect. Forty-three subjects participated in this additional control condition. Again, outcomes are very similar to those in the individual condition: 46.5% of subjects decided to buy the ticket accepting the killing of a mouse. This fraction is significantly different from fractions in both market conditions (bilateral market, $P = 0.021$, $n = 79$ and multilateral market, $P = 0.003$, $n = 97$, two-sample test of proportions). Unsurprisingly, the killing rate is not significantly different from the individual condition ($P = 0.946$, $n = 167$, two-sample test of proportions).

Third, let us comment on why we used the minimum trading price as our main dependent variable to assess a seller's willingness to kill a mouse in markets [see also (*16*)]. Very likely, traders tried to negotiate higher prices than their reservation values to realize positive gains from trade. This should be the case for any market situation with information rents in which reservation values are private, as in our case. For example, a seller in the bilateral market with a reservation value of 5 euros is unlikely to actually trade at 5 euros. Instead, he should try to negotiate higher prices. We therefore think that concluded prices provide an upper bound for the sellers' reservation values. One may also argue that using the minimum concluded price could bias results if sellers made mistakes, erroneously agreeing to trade at prices lower than they would have actually liked to accept. We believe that it is unlikely that traders made such mistakes, because trading involved a deliberate decision to either accept or make offers. Yet, accounting for this possibility, we also calculated median values of concluded trading prices below or equal to 10 euros. The corresponding killing fractions are 67% for the bilateral market and 76% for the multilateral market, very similar to the ones reported in Fig. 1. These fractions are statistically significantly different from the individual condition ($P = 0.029$ for bilateral market and $P < 0.001$ for multilateral market, two-sample test of proportions).

We stress another aspect of our results: following the methodological standards in experimental economic, it was essential to incentivize subjects' decisions in the individual condition, i.e., subjects needed to receive money according to their decisions. Otherwise, a comparison with market outcomes would have been misleading. For subjects, it would be "cheap" to claim that they are moral if being moral costs nothing. The comparison of the individual treatment with markets did therefore not involve paying money versus not paying money. Yet, introducing a money prime may already lower moral standards, as several studies have pointed out. For example, it has been shown that material primes or labels reduce helpfulness or prosocial behavior and increase competitiveness (*29*–*31*) and that an economics background correlates with selfishness (*32*). Hence, the impact of markets on moral behavior may in general be even more pronounced than our study suggests.

We have shown that market interaction displays a tendency to lower moral values, relative to individually stated preferences. This phenomenon is pervasive. Many people express objections against child labor, other forms of exploitation of the workforce, detrimental conditions for animals in meat production, or environmental damage. At the same time, they seem to ignore their moral standards when acting as market participants, searching and buying the cheapest electronics, fashion, or food, and thereby consciously or subconsciously creating the undesired negative consequences to which they generally object. We have shown that this tendency is prevalent already in very simple bilateral trading where both market sides are fully pivotal in that if they refuse to trade, the mouse will stay alive. In markets with many buyers and sellers, diffusion of being pivotal for outcomes adds to moral decay. This "replacement" logic is a common feature of markets, and it is therefore not surprising that the rhetoric of traders often appeals to the phrase that "if I don't buy or sell, someone else will."

In the experiment, subjects were fully aware of the consequences of their decisions in that they could save the life of a mouse if they refused to accept a monetary amount. Our findings therefore suggest that appealing to morality has only a limited potential for alleviating negative market externalities. For example, anti–child-labor or environmental protection campaigns may not be that effective because markets for goods undermine the relevant social values. The results also suggest why societies do ban markets for certain "repugnant" activities (*33*). Historically, dispute about the marketability and the appropriateness of markets has led to some of the most fundamental upheavals within modern societies. For example, the abolishment of trading human beings was a major issue in the American Civil War. Martin Luther's critique of the trade of indulgences, in which buyers and sellers exchanged money for the freedom from God's punishment for sin, was a key element of the Protestant Reformation. Karl Marx's idea that capital stock should not be tradable, that it must belong to the workers themselves, is a cornerstone of communist ideology. With the recent financial crisis, discussion has arisen about the appropriateness of markets for complex financial products like derivatives involving high risks. Stock traders have been criticized for riding bubbles and for cashing in short-term profits without thinking about possible negative long-term impacts on companies, as well as on society in general.

Markets have tremendous virtues in their capability to generate information about scarcity and to allocate resources efficiently. The point of this study is not to question market economies in general. Indeed, other organizational forms of allocation and price determination such as in totalitarian systems or command societies do not generically place higher value on moral outcomes (*34*). Furthermore, the development of a complex market structure may require and therefore correlate with the prevalence of moral and social values, such as trust and cooperativeness. Results confirming this intuition, in line with the *Doux-commerce Thesis* (*35*), are expressed, e.g., by Kenneth Arrow (*36*). However, focusing on the causal effects of institutions, we show that for a given population, markets erode moral values. We therefore agree with the statement quoted at the beginning that we as a society have to think about where markets are appropriate—and where they are not.

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17. Comparable demonstration videos showing the killing process are publicly available at laboratories conducting animal research. The video presented to subjects showed how mice are gassed.
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Supplementary Materials

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Supplementary Text
Figs. S1 and S2
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Rational HIV Immunogen Design to Target Specific Germline B Cell Receptors

Joseph Jardine,[1,2,3,4]* Jean-Philippe Julien,[2,3,5]* Sergey Menis,[1,2,3,4]* Takayuki Ota,[1] Oleksandr Kalyuzhniy,[1,2,3,4] Andrew McGuire,[6] Devin Sok,[1,2,3] Po-Ssu Huang,[4] Skye MacPherson,[1,2,3,4] Meaghan Jones,[1,2,4] Travis Nieusma,[2,3,5] John Mathison,[1] David Baker,[4] Andrew B. Ward,[2,3,5] Dennis R. Burton,[1,2,3,7] Leonidas Stamatatos,[6,8] David Nemazee,[1] Ian A. Wilson,[2,3,5,9] William R. Schief[1,2,3,4]†

Vaccine development to induce broadly neutralizing antibodies (bNAbs) against HIV-1 is a global health priority. Potent VRC01-class bNAbs against the CD4 binding site of HIV gp120 have been isolated from HIV-1–infected individuals; however, such bNAbs have not been induced by vaccination. Wild-type gp120 proteins lack detectable affinity for predicted germline precursors of VRC01-class bNAbs, making them poor immunogens to prime a VRC01-class response. We employed computation-guided, in vitro screening to engineer a germline-targeting gp120 outer domain immunogen that binds to multiple VRC01-class bNAbs and germline precursors, and elucidated germline binding crystallographically. When multimerized on nanoparticles, this immunogen (eOD-GT6) activates germline and mature VRC01-class B cells. Thus, eOD-GT6 nanoparticles have promise as a vaccine prime. In principle, germline-targeting strategies could be applied to other epitopes and pathogens.

Protection against disease by nearly all licensed vaccines is associated with induction of antibodies (*1*). Viruses with high antigenic diversity, such as HIV, influenza virus, and hepatitis C virus, pose major challenges for vaccine development (*2*). Most exposed surfaces on the Envelope glycoproteins (Env) of these viruses are hypervariable or shielded by glycans (*3*), and traditional vaccine approaches tend to induce neutralizing antibodies against only a small subset of viral strains (*4*–*6*). However, discoveries of bNAbs against each of these viruses have identified conserved epitopes as leads for vaccine design (*2*), and structural analysis has provided atomic definition for many of these epitopes (*7*, *8*). Structure-based approaches are, therefore, needed to reverse-engineer vaccines capable of inducing bNAbs against these conserved epitopes (*9*).

High-potency VRC01-class bNAbs against the HIV gp120 CD4 binding site (CD4bs) have been isolated from several individuals infected with different strains of HIV-1 (*10*–*12*). VRC01-class bNAbs all derive from the human VH1-2*02 variable heavy gene but differ substantially in amino acid sequence and complementarity-determining region H3 (CDRH3) length and use a few different variable light chain genes (figs. S1 and S2). Structural studies have revealed that VRC01-class bNAbs employ a common mode of gp120 binding in which the VH1-2 framework mimics CD4 and provides additional electrostatic and hydrophobic contacts (Fig. 1A) (*12*–*15*). A short CDRL3 loop is also required for interaction with gp120 V5 and Loop D, and a CDRL1 deletion in many VRC01-class bNAbs avoids clashes with a glycan linked to Asn^{276} (N276) on loop D.

Vaccine design to induce VRC01-class bNAbs is attractive because VH1-2 genes are estimated to be present in ~2% of the human Ab repertoire (*16*) and, even considering restrictions on light chain usage, suitable precursors should be present in the naïve B cell repertoire of most individuals. However, predicted germline (GL) precursors for VRC01-class bNAbs exhibit no detectable affinity for wild-type Env (*11*, *13*) (Table 1 and table S1), a potential explanation for the rarity of VRC01-class bNAbs in HIV-1 infection (*13*). More important, wild-type Env constructs lacking GL affinity are poor vaccine candidates to prime VRC01-class responses, because they are unlikely to reliably stimulate GL precursors to initiate antibody maturation.

Immunogen Design Strategy

To address the problem described above, we modified the CD4bs on a minimal, engineered outer domain (eOD) (*17*) to produce a germline-targeting vaccine prime (Fig. 1) with two important binding properties: (i) moderate affinity for multiple predicted VH1-2*02 GL-Abs to enhance the ability to activate VH1-2 GL B cells with appropriate light chains; (ii) high affinity for VRC01-class bNAbs to provide an affinity gradient to guide early somatic mutation toward

[1]Department of Immunology and Microbial Science, The Scripps Research Institute, La Jolla, CA 92037, USA. [2]International AIDS Vaccine Initiative Neutralizing Antibody Center, The Scripps Research Institute, La Jolla, CA 92037, USA. [3]Center for HIV/AIDS Vaccine Immunology and Immunogen Discovery, The Scripps Research Institute, La Jolla, CA 92037, USA. [4]Department of Biochemistry, University of Washington, Seattle, WA 98195, USA. [5]Department of Integrative Structural and Computational Biology, The Scripps Research Institute, La Jolla, CA 92037, USA. [6]Seattle Biomedical Research Institute, Seattle, WA 98109, USA. [7]Ragon Institute of Massachusetts General Hospital, Massachusetts Institute of Technology, and Harvard, Cambridge, MA 02129, USA. [8]Department of Global Health, University of Washington, Seattle, WA 98109, USA. [9]Skaggs Institute for Chemical Biology, The Scripps Research Institute, La Jolla, CA 92037, USA.

*These authors contributed equally to this work.
†Corresponding author. E-mail: schief@scripps.edu