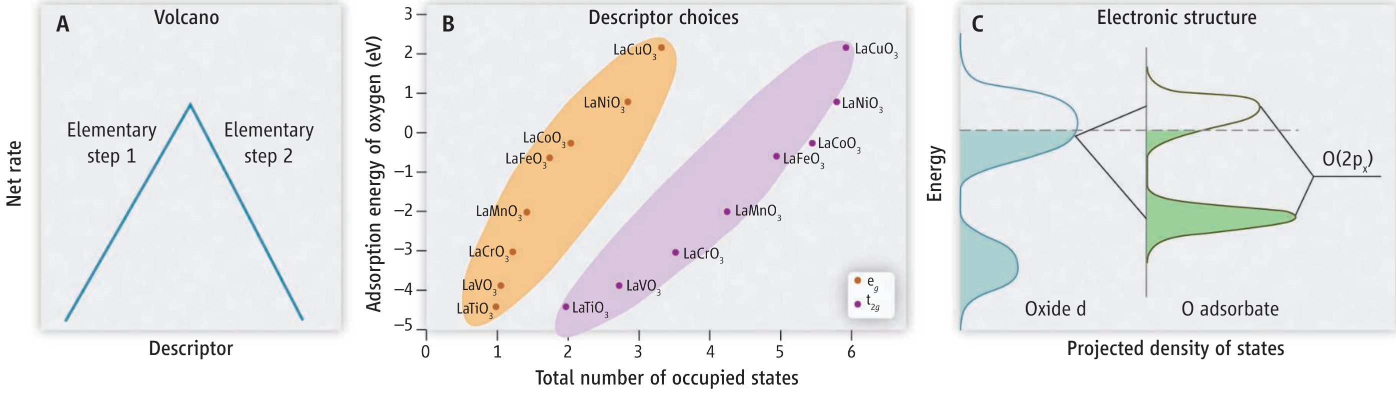

Discovering descriptors for catalyst performance. (**A**) For many catalytic reactions, intrinsic catalyst parameters, or descriptors, can be identified (such as changes in electronic properties created by using different metals) that lead to a "volcano plot" for the reaction rate. (**B**) Suntivich *et al*. identified the occupation of d states with e_g symmetry as a good descriptor for the oxygen evolution reaction over metal oxide catalysts. We include DFT calculations (*7*) to show that the descriptor can also be the t_{2g} symmetry occupation or the adsorption energy of oxygen. (**C**) Schematic of the formation of a bond between an oxygen adsorbate level and the d states of the oxide, explaining why the occupancy of the d states correlates with the oxygen adsorption energy and hence with the catalytic activity.

become more difficult because surface-oxygen bonds are ruptured.

This tradeoff was exploited and led to the identification of an optimum surface-oxygen interaction energy that maximizes the overall rate. This approach follows the Sabatier principle (*5*), which states that the interaction between the catalysts and the adsorbate should be neither too strong nor too weak, but introduces the important new aspect of quantifying this interaction strength (*3*). The electronic structure of these solid oxides is described by band theory. Unlike an isolated molecule, the valence bands and conduction bands can be partially filled with electrons, which is described as a density of states (DOS).

We show in the figure, panel B, that the notion that the surface-oxygen bond energy scales with the e_g occupation is borne out by direct DFT calculation. In addition, there is a similar correlation with the occupancy of the other d symmetry component, t_{2g}. A more detailed analysis of the electronic structure reveals that the occupation of e_g and t_{2g} states has two contributions, one from occupied valence band states and one from occupied conduction band states. The best correlation is with the number of occupied conduction band states. Hence, it is the reactive states near the Fermi level (which separates the occupied from the unoccupied states) that are responsible for the occupancy of e_g/t_{2g} states being a good descriptor.

The interaction between these surface states and the O 2p adsorbate levels gives rise to bonding and antibonding O states (see the figure, panel C). The adsorption strength will depend on the occupancy of these bonding and antibonding O states and will be strongest when the O bonding states are completely occupied while the O antibonding states are completely unoccupied. This bonding interaction resembles the ones between an adsorbate and a transition metal surface, in which the d-band center of the metal is a descriptor (*3*), and between an adsorbate and a transition metal carbide surface, in which the center of the surface resonance states is a descriptor (*6*).

The work of Suntivich *et al*. provides a new approach for science-based catalyst design and for finding cheap and efficient alternatives to the known inorganic catalysts for water splitting. Their work is an important step toward sustainable fuel production, and could also provide insights into more direct approaches in which incident light helps to power the water-splitting process.

References and Notes

1. H. Dau *et al*., *ChemCatChem* **2**, 724 (2010).
2. J. Suntivich *et al*., *Science* **334**, 1383 (2011); 10.1126/science. 1212858.
3. J. K. Nørskov *et al*., *Nat. Chem.* **1**, 37 (2009).
4. I. C. Man *et al*., *ChemCatChem* **3**, 1159 (2011).
5. P. Sabatier, *Ber. Deutsch. Chem. Ges.* **44**, 1984 (1911).
6. A. Vojvodic *et al*., *Phys. Rev. Lett.* **103**, 146103 (2009).
7. A. Vojvodic *et al*., *J. Chem. Phys.* **134**, 244509 (2011).

8. We thank the Office of Basic Energy Sciences, U.S. Department of Energy, for support through the SUNCAT program.

10.1126/science.1215081

ECONOMICS

Can Integration Tame Conflicts?

Lorenz Goette[1] and Stephan Meier[2]

Integration efforts can increase cooperation between ethnic or religious groups if competition is avoided.

Civil wars between ethnic or religious groups have cost millions of lives in recent history (*1*). In Bosnia and Herzegovina alone, tens of thousands were killed and millions displaced in the war between 1992 and 1995. However, although intense hatred against other groups can lead to tragedy, it often seems to come in tandem with stronger altruism and cooperation within one's own group (*2*, *3*). This combination may have played a key role in early human development (*4*). Are there ways to mitigate group conflict while at the same time harvesting the potential benefits from stronger cooperation within groups? A report by Alexander and Christia on page 1392 of this issue (*5*) suggests that the answer is yes, under the right circumstances.

The conditions under which conflicts emerge between groups are not well understood. Two African tribes—the Chewas and the Tumbukas—provide a stark example: They get along with each other in Zambia, but relations are hostile in the neighboring state of Malawi (*6*). Ethnoreligious diversity alone does not always create conflict. The environment in which different groups interact seems to matter for whether the dark side of group membership emerges.

It has been suggested that integration of different previously warring groups can mit-

[1]Faculty of Business and Economics, University of Lausanne, 1015 Lausanne-Dorigny, Switzerland. [2]Graduate School of Business, Columbia University, 3022 Broadway, New York, NY 10027, USA. E-mail: lorenz.goette@unil.ch; sm3087@columbia.edu

igate conflict and restore intergroup cooperation (*7*), but there is no clean evidence so far. Comparing groups that have chosen to segregate with groups that have chosen to integrate provides limited insight, because it may be the absence of conflict that causes integration, not the other way around.

Alexander and Christia studied the behavior of students belonging to two ethnic groups, Catholic Croats and Muslim Bosniaks, in post-war Bosnia and Herzegovina. In the city of Mostar, two previously segregated school were integrated, while two other sites were left segregated. Integration happened for purely logistical reasons, thus any differences in behavior by the students from segregated and integrated schools can be attributed to a causal effect of integration. To measure these effects, the students participated in economic experiments that pit an individual's self interest against the welfare of other participants. These others sometimes belong to the same ethnic group, and sometimes not, at integrated as well as segregated schools. This allows the authors to measure the willingness to cooperate with others.

Previous studies have shown that, although some individuals are willing to cooperate, many are not (*8*); individuals typically cooperate more if they interact with someone from their own group (*2*). Alexander and Christia also ran experiments that let participants sanction others by reducing their payoff at a personal cost. Such sanctions can reinforce group cooperation if they are directed against selfish individuals who otherwise wouldn't cooperate (*8–10*). However, the availability of sanctions also raises the prospect of inflicting harm onto others for no good reason, which can then lead to an even worse outcome than when sanctioning is not possible.

Alexander and Christia show cooperation to be significantly hampered when people interact with members of another ethnic group. In mixed groups, contributions to the public good are much lower than in homogeneous groups. These results replicate previous findings (*2*). However, the authors also show that an integrative environment removes such parochialism, leading to the same cooperation rates within and between ethnoreligious groups. Furthermore, integration modulates the effectiveness of sanctions. Alexander and Christia find that giving means to sanction others is completely ineffective in segregated environments. Integration brings back the benefits of sanctioning, leading to high cooperation rates.

The nature of group interactions thus depends critically on the context. In segregated societies, cooperation is strongly obstructed by group diversity, whereas in an integrated environment, even mixed groups can achieve high levels of cooperation.

Given that the proper functioning of a sanctioning mechanism is a critical part of sustaining high cooperation and preventing conflict, the finding that sanctioning seems to crucially depend on the environment is important. To increase contributions, sanctions have to be directed toward selfish individuals who refuse to cooperate. However, in certain contexts, people sanction indiscriminately—a behavior termed "antisocial punishment" (*11*)—thereby completely destroying the benefits of sanctions. The evidence reported by Alexander and Christia suggests that segregated societies may achieve lower levels of cooperation and trigger conflicts because sanctions are not working properly. This is consistent with the evidence that antisocial punishment is especially pronounced in societies with close-knit social networks (*11*). Integration can turn sanctioning behavior back to being prosocial and less parochial.

PHOTO CREDIT: LUCERTOLONE/SHUTTERSTOCK

Cooperation in the city of Mostar. In an experiment involving school children, Alexander and Christia show that integration of different enthnoreligious groups can increase cooperation to the same levels as within groups.

Is integration sufficient to overcome conflict between groups? In the setting of Alexander and Christia, the answer is yes. In others, it is not. Goette *et al*. (*12*) examine the behavior of different, randomly formed platoons in the Swiss army that share the same facilities. In their baseline conditions, they find that sanctions are used to protect one's own platoon, not to attack others. Yet, if those same platoons interact in an experimentally imposed competitive environment, things take an ugly turn: Sanctions become vicious and display strong punishment of other groups, even if they cooperate. Thus, competition between groups can lead to conflicts along group lines even in integrated environments.

Integration efforts thus have to tread a fine line of bringing different groups together without creating a sense of competition between them. Alexander and Christia make a valuable contribution to a better understanding of this phenomenon, but more research is needed to understand what other contextual factors can mitigate group conflicts.

References

1. C. Blattman, E. Miguel, *J. Econ. Lit.* **48**, 3 (2010).
2. L. Goette *et al*., *Am. Econ. Rev.* **96**, 212 (2006).
3. H. Bernhard *et al*., *Nature* **442**, 912 (2006).
4. J. K. Choi, S. Bowles, *Science* **318**, 636 (2007).
5. M. Alexander, F. Christia, *Science* **334**, 1392 (2011).
6. D. N. Posner, *Am. Polit. Sci. Rev.* **98**, 529 (2004).
7. M. Sherif *et al*., *Intergroup Conflict and Cooperation: The Robbers Cave Experiment* (University Book Exchange, Norman, OK, 1961).
8. E. Fehr, S. Gächter, *Nature* **415**, 137 (2002).
9. S. Gächter *et al*., *Science* **322**, 1510 (2008).
10. E. Ostrom *et al*., *Am. Polit. Sci. Rev.* **86**, 404 (1992).
11. B. Herrmann *et al*., *Science* **319**, 1362 (2008).
12. L. Goette, D. Huffman, S. Meier, M. Sutter, *Manage. Sci.* 10.1287/mnsc.1110.1466 (2011).

10.1126/science.1215617

Published by AAAS