Articles

Macroeconomics in an Open Economy

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The customary treatment of national economies as closed and self-contained must be substantially modified to allow for those economies that typically trade goods, services, and securities with other countries in increasing volume. Open economy macroeconomics is essential to understanding the major events of the U.S. economy over the past half dozen years. Both the sharp rise in the dollar and the unprecedentedly large U.S. trade deficit are linked to the U.S. budget deficit, as is the drop in the rate of inflation.

MACROECONOMICS DEALS WITH THE ENTIRE NATIONAL economy, rather than with markets for particular products, and has been principally concerned with explaining fluctuations over time in output, employment, and the general level of prices. Most theoretical work in macroeconomics is modeled on a closed economy, that is, one that has no economic interaction with the rest of the world. Open economy macroeconomics, therefore, is the subbranch of macroeconomics that allows for international trade in goods and services and for movements of capital across national boundaries in response to economic incentives. Theoretical macroeconomics differs from the main body of economics by characterizing the economy as a whole on the basis of empirical observation within a framework of consistent national economic accounts. This contrasts with microeconomic theory, which derives behavioral relationships on the assumption that decision-making units, families or firms, are maximizing some entity of value, such as profits.

A Simple Model for a Closed Economy

A widely used framework for exploring macroeconomics focuses attention on two macroeconomic variables, the level of national income, Y, which in a closed economy equals national output, and the rate of interest, r. The framework proceeds from two market-clearing conditions:

$$E(Y, r) = Y \quad (1)$$

$$M/P = L(Y, r) \quad (2)$$

Here E is total expenditure on goods and services in a given period of time, M is the supply of money, and P is the national price level. Equation 1 shows that in equilibrium total expenditure on goods and services must equal total income and that income and the interest rate will adjust so as to bring this about. Expenditure is assumed to be negatively related to interest rates but positively related to income. To maintain the equality, higher interest rates require lower levels of income. This balance in the market for goods and services is maintained along a downward sloping schedule such as GG in Fig. 1.

The supply of money (economists do not agree on the best definition of this term) is assumed to be determined exogenously by the monetary authorities. L is the public's demand for the same money, depending positively on income (more money is needed for a higher level of transactions) and negatively on the rate of interest (because higher r, which is the interest on bonds or other financial assets, leads households to conserve their lower yielding money in order to hold less of their wealth in the form of "money"). Equilibrium in the money market thus leads to an upward-sloping schedule such as LL in Fig. 1. The intersection of the two schedules determines the interest rate and the level of income that will clear both the goods and financial markets. Employment is determined by the level of output.

This framework has been widely used for examining various changes introduced into an economy. For example, an increase in government expenditure not offset by a tax increase will shift the GG schedule to the right, say, to G′G′, and this will lead to a rise in national income and the rate of interest, from K to K′ in Fig. 1. An autonomous investment boom (or, in an open economy, an export boom) would cause a similar shift in the GG schedule. An increase in the supply of money by the central bank will shift the LL schedule to the right and thus lead to a rise in national income and a fall in the interest rate.

This formulation does not account for the price level. It is Keynesian in flavor and arose from an attempt by the British economist and Nobel laureate John Hicks to characterize the macroeconomic equilibrium underlying the system put forward by J. M. Keynes in 1936 (*1*). Keynes' theory was written at a time when it was assumed that prices (more accurately, money wages) would not respond either to an increase or to a decline in output in the short run. That assumption has been one of the most controversial ones in macroeconomics, especially after the rapid inflation of the 1970's. It is possible, however, to adapt this framework to circumstances when prices are variable and output is fixed at "full-employment" in the short run, but output is variable in the long run in response to new investment. The transition dynamics from "short" to "long" run are, however, complicated and not well developed (*2*).

This general framework of analysis permits comparison of short-run macroeconomic equilibria before and after some change to the economy—an exercise in comparative statics—but it lacks dynamics, that is, the path of key variables moving from one equilibrium to another over time. One way to deal with the dynamics is to assume that all prices are fully flexible and demand equals supply continuously, with the implication that there is no such thing as involuntary unemployment. Many unemployed workers would be astonished at such a conclusion. Moreover, the assumption of instantaneous or rapid clearing of markets makes it difficult to understand many features of actual economies, such as the liquidation of inventories in an economic downturn or the granting of noncontractual pay increases in a recession, when no new hiring is taking place (*3*).

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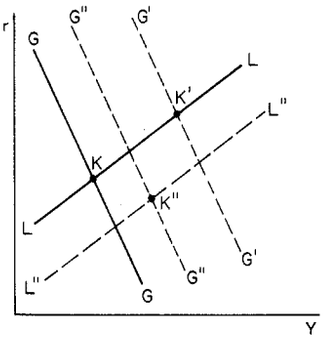

Fig. 1. Simultaneous determination of income, Y, and the interest rate, r.

The formalization offered above pertains to a self-contained economy—one that does not trade with the rest of the world. Indeed, economics is generally taught in the United States as if the United States were a closed economy, with only brief mention given to the importance of recognizing that the United States trades in goods, services, and assets with the rest of the world. The openness is not usually integrated into the analysis. Moreover, the widespread use of American texts around the world suggests that a closed economy framework is taught in many other countries as well.

Adapting the Framework to an Open Economy

Analysis of macroeconomic events must be adapted to take the increasing openness of national economies into account, and this analysis involves greater complexity. The framework must incorporate foreign buyers as a source of demand for domestic goods and foreign sellers as a source of supply. There may be net inflows or outflows of funds, which create the possibility that total expenditure on goods and services may exceed or fall short of total income and output, as residents (including government) borrow from or lend to the rest of the world. If exchange rates are flexible, that is, free to respond to market pressures, the effects of fluctuations on demand for both goods and financial assets must be considered. With flexible exchange rates, it is also necessary to specify expectations about future values of the exchange rate, since prospective movements in the exchange rate may influence current behavior.

How should the macroeconomic analysis be amended? First, the GG schedule must include net foreign trade, and its position can be influenced by the exchange rate, since a more depreciated currency will generally enlarge the foreign demand for our country's goods. Equation 1 becomes

$$Y = E(Y, r, e) + X(Y^*, e) - I(Y, e) \quad (3)$$

Here X is exports, I is imports, e is the exchange rate (units of home currency per unit of foreign currency), and an asterisk signifies the rest of the world (*4*). Any excess of imports over exports of goods and services must be "financed" by the sale of securities, such as stocks, bonds, and interest-bearing bank accounts, to foreigners. Indeed, the attraction of foreign securities because of their safety or yield may play a decisive role in determining the exchange rate, which in turn influences trade flows and production. The growth of international capital mobility over the past two decades has been one of the most notable changes in the international economy, and it played a major role in the move by large countries from fixed to flexible exchange rates in the early 1970's. These developments have led to new lines of economic theorizing.

Second, the interest rate r^* on foreign bonds and on domestic bonds will influence the demand for money. Opening the economy introduces two further considerations bearing on the demand for money. (i) The overall price level is no longer the same as the price level for domestic output, since the former includes imported goods and their prices in domestic currency may be changed by movements in the exchange rate. (ii) Total expenditure need not be equal to total income, as it is in a closed economy, and it is plausible that expenditure rather than income influences the demand for domestic money. The problem is compounded further for the United States because foreigners hold hundreds of billions in interest-bearing U.S. dollar balances, many of them outside the United States, and although exact information is not available, foreigners also probably hold more than $20 billion in U.S. currency outside the United States. Should such holdings be counted as part of the U.S. money supply or not? (The former are not included in various measures of the U.S. money supply; the latter are.) But if they are not in the U.S. money supply, in whose money supply are they?

Third, it is in principle necessary to "close" the model by specifying behavioral relations for the rest of the world to allow for the determination of Y^*, P^*, and r^* within the economic system. The usual practice for classroom or textbook exposition is to assume that our country is so small that its influence on the rest of the world can plausibly be neglected, so Y^*, P^*, and r^* can be taken as exogenous factors of the economy. Changes in these variables are a source of disturbance to our economy. The small-country assumption is not plausible for the United States, however, which still accounts for about one-quarter of the gross world product. Analysis of the U.S. economy should take into account its impact on economic developments in the rest of the world and the feedback of those developments on the U.S. economy.

Finally, if the exchange rate is an important, rapidly changing variable, some allowance must be made for the influence on today's behavior of expected future changes in the exchange rate. Three assumptions compete in this question. (i) The present exchange rate is expected to last indefinitely. (ii) The present exchange rate is expected to converge exponentially at some rate on the long-term equilibrium exchange rate, as determined by the model [usually on the basis of "purchasing power parity" (PPP), a comparison of the domestic price level with that prevailing in the rest of the world]. (iii) The exchange rate is expected to be what the model will determine it to be in every period; this last assumption is sometimes called "rational expectations."

Under a system of freely floating exchange rates, the exchange rate is a flexible price that is influenced by what happens in the markets for financial assets as well as the markets for goods. As such, it is responsive to changes in market views about assets denominated in one currency relative to those denominated in other currencies. It can thus jump substantially, like stock prices, in response to new information that bears on future movement of exchange rates. Suppose, for example, the central bank takes an action that leads to a fall in domestic interest rates. Then holders of domestic bonds will find foreign bonds more attractive (assuming that the yield of foreign bonds has not changed). Their attempt to purchase foreign bonds will lead to an immediate depreciation of the home currency, overshooting its new medium-run equilibrium value to the point at which expected future appreciation of the home currency compensates for the difference in domestic and foreign interest rates. This situation is portrayed in Fig. 2, when the bond purchase occurs at time t_0. The exchange rate e, measured in units of domestic currency per unit of foreign currency, immediately rises (that is, the home currency depreciates), and thereafter it falls gradually as the newly created desire for higher yielding foreign bonds is satisfied through an emerging trade surplus. (In terms of Fig. 1, the currency depreciation after a rightward shift of LL will also shift GG to the right.) If the economy is near full utilization of its productive capacity, domestic prices P will rise over time, so that by t_1 the real exchange rate (the exchange rate adjusted for changes in the price

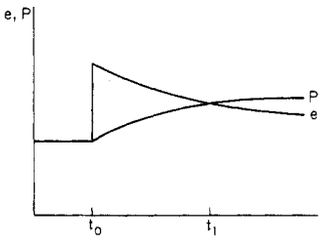

Fig. 2. Time, t, profile of the exchange rate, e, and prices, P, after an open market purchase by the central bank.

level) is restored to what it was before t_0. In terms of Fig. 1, both LL and GG shift gradually back to the left. [It is assumed here that foreign prices and interest rates remained unchanged (*5*).]

An implication of such "overshooting" is that there will be much variability in real exchange rates, and hence in international competitiveness, owing to developments in financial markets. If wages and other costs are not fully flexible, competitiveness as reflected in profit margins will vary. This variation in profitability for reasons arising outside each industry may reduce investment or encourage a worldwide diversification of the activities of business firms, so as to reduce the exchange risk. Moreover, differing sectors of the economy are subject to differing degrees of foreign competition, so movements in exchange rates affect relative prices within the economy as well. If a country's currency appreciates, its "tradable" sector—those firms subject to foreign competition either in export markets, such as U.S. grain farmers, or in the home market, such as U.S. textiles—will be put under competitive pressure and may suffer accordingly. In contrast, its nontradable sector, for example, health care or the defense industry, will not feel such competitive pressure and indeed may benefit from the same factors, such as expansionist fiscal policy, which encouraged the currency to appreciate. Over time, resources will shift from the tradable to the nontradable sectors.

As the complexity of the economy grows, especially regarding the number of ways in which people can hold assets and the substitutability among those assets, stronger (and more limiting) assumptions must be made about the structure of the economy in order to determine even the sign of the impact on output, prices, and the exchange rate in response to specified changes in one of the exogenous variables (*6*). Examples of these variables include weather, strikes, technical innovation, or policy actions under the control of governments. Since complexity greatly increases the number of theoretically possible outcomes in response to outside shocks or policy actions, the likely outcome must be determined empirically. This process has only recently begun for open economies under flexible exchange rates, partly because the length of experience is not long and because serious theorizing about this kind of regime is relatively recent. Economists, like astronomers and meteorologists, must closely observe the environment as it exists, and then make careful inferences. They cannot, like most scientists, set up experiments in which many of the potentially influential variables are closely controlled. Yet they are expected to make judgments about consequences of policy changes. Under these circumstances, economists have resorted increasingly to numerical simulations on large-scale economic models. To provide the detailed quantitative structure to such models it is necessary to estimate the coefficients without the benefit of controlled experiments. That is the task of econometricians, who operate on the assumption that the economic structure is unchanged during the period of estimation, a problematic assumption for economies that are constantly undergoing evolutionary change. An alternative approach is to make informed guesses about the values of the coefficients and to test the sensitivity of the results to these guesses through simulation of alternative values (*7*).

Two of the key empirical questions for open economy macroeconomics concern the degree of international mobility of financial capital and the relation of the exchange rate to national prices. (Of course, the flexibility of real wages, the responsiveness of prices to weakness in overall demand, and the sensitivity of investments, savings, and the demand for money to changes in interest rates are also important in open economies.)

The mobility of financial capital determines how closely interest rates and other financial variables are connected between countries, and therefore how much changes in monetary conditions will alter the exchange rate and influence economic activity through the exchange rate channel. Various factors affect the international mobility of financial capital. The first is the presence or absence of exchange controls, government-imposed impediments to the inward or outward movement of funds. Broadly speaking, controls on capital movements are absent for the United States, Canada, West Germany, Great Britain (since 1979), Japan (since 1980), Switzerland, and the Netherlands, but most developing countries and many industrialized countries still prohibit or sharply limit the outflow of capital in important ways.

The second is the extent to which similar assets—for example, fixed interest securities, such as short-term time deposits or government bonds—are seen by investors as highly substitutable for one another, despite their different jurisdictions of issue (hence legal framework) and despite the fact that assets are denominated in different currencies. Empirical work has focused on the relation

$$r = r^* + \dot{e}_e + \rho \tag{4}$$

where for roughly comparable financial claims, r is the interest rate in one country, r^* is the interest rate in the second country, $\dot{e}_e$ is the expected change in the exchange rate between the two currencies over the maturity of the asset, and ρ is a risk premium. Tests of $r = r^*$ do well for comparable securities traded in the major markets, such as New York and London, that are denominated in the same currency, but very poorly when denominated in different currencies. These results suggest that jurisdiction (at least among major markets) is relatively unimportant but currency of denomination is important in reducing substitutability.

Expected changes in exchange rates are not directly observable. It is appealing to assume, on average, $\dot{e}_e = \dot{e}$; that is, market participants estimate correctly the change in exchange rates that will take place. Tests of this proposition on the assumption that $\rho = 0$ do not perform at all well. Efforts to introduce a well-behaved risk premium (well-behaved in the sense that it is determined in some plausible, simple way) on the assumption that $\dot{e}_e = \dot{e}$ also have not succeeded (*8*). One must conclude that denomination in different currencies sharply differentiates securities in the eyes of investors, but the precise nature of the influence has not yet been discovered. The limited amount of direct survey data on expected changes in exchange rates does not help predict changes. Financial specialists said that they expected a drop in the dollar against other major currencies over the period 1981–1984, yet the dollar, influenced by the collective behavior of these and other financial operators, actually appreciated during much of this period (*9*).

It is possible that participants in financial markets have in mind a long-run equilibrium exchange rate ($\bar{e}$) and that they expect the market rate to converge gradually on that equilibrium rate over time, as shown by

$$\dot{e} = \alpha(e - \bar{e}) \tag{5}$$

where α indicates the rate of convergence.

But what determines the long-term equilibrium rate? In principle, the answer is all variables exogenous to the economic system, along with the structure of relations among variables. If there were some

simple binding constraint on this complex outcome, the exchange rate could be set by only a few relevant variables in the system. The leading candidate for this role is the purchasing power parity of the two currencies in terms of goods and services. Usually PPP in the period under scrutiny is compared with that of some base period assumed to have been in equilibrium. Unfortunately, PPP does not explain movements in exchange rates among the major currencies very well, either in the short run of 1 or 2 years or in the medium run of 5 to 10 years (*10*).

Despite the weak empirical support for some of the detailed propositions of open economy macroeconomics, these theories offer some insights into the functioning of modern economies, which may be overlooked or neglected when the model of a closed economy plus a foreign trade sector is used. In particular, they offer some interpretation of the macroeconomic events in the United States over the past 5 or 6 years.

Compared with the closed economy approach, fiscal expansion in an economy with high international capital mobility and flexible exchange rates may be less effective in stimulating overall demand because it leads to an appreciation of the currency. It is also less inflationary in the short run and might even lead to a reduction of the overall price level even while domestic output is expanding. Expansionist fiscal action is less likely to "crowd out" investment when the economy is operating close to its capacity because it induces inflows of foreign funds that help to sustain both domestic investment and the budget deficit. Exports are crowded out instead. In Fig. 1, a given fiscal expansion in a regime of floating exchange rates will shift GG only as far as G″G″ because of the currency appreciation, and the consequential drop in prices will shift LL to L″L″, leading to a new equilibrium at K″ (*11*).

Monetary policy too will be affected by the openness of the economy and flexible exchange rates. A given increase in the money supply may be more effective at expanding demand because it leads to currency depreciation and a decline in interest rates. However, price increases from this source of demand expansion will also show up sooner because of depreciation of the currency. In addition, the sectoral impact of monetary policy will differ. In a relatively closed economy, the impact falls on the interest or credit-sensitive sectors, such as housing. In an open economy, it affects all tradable goods, because of the exchange rate.

Interpreting Developments in the U.S. Economy

These stylized results apply also to other disturbances that have structural similarities to changes in fiscal or monetary policy. They do not hold up under all degrees of complexity; but they are reasonably robust, and they help to interpret economic developments in the United States during the past half dozen years, when the U.S. economy demonstrated a marked degree of openness (*12*).

The Federal Reserve System adopted a tighter monetary policy in late 1978 and changed its mode of operation in November 1979 to concentrate on money magnitudes rather than on other indicators of monetary conditions, especially interest rates. One consequence was an appreciation of the dollar from the low values of 1978. With the tax reduction and defense buildup of 1981, the United States adopted an expansionary fiscal policy. Slightly earlier, in 1979 and 1980, Great Britain, West Germany, and Japan adopted policies of fiscal contraction. The result of this configuration of policies was a sharp relative increase in interest rates on U.S. securities. The attraction of U.S. securities was enhanced further by the relaxation of exchange controls in Great Britain and Japan and by political jitters in Europe arising from extensive nationalizations by the new socialist government in France and by political turmoil in Poland during 1981. The combination of high U.S. interest rates and changes in asset preferences led to a sharp appreciation of the dollar against other major currencies as foreigners attempted to buy dollar-denominated assets. The tight U.S. monetary policy at first led the United States—and the world—into a deep recession in 1982. The expansionist fiscal policy, accompanied in late 1982 by some monetary easing, led to a marked economic recovery in the United States in 1983–84.

The U.S. dollar appreciated about 20% against other major currencies (weighted by their importance in U.S. trade) between 1980 and 1982. This appreciation contributed to a sharp drop in U.S. exports, which exceeded the drop in U.S. production during this period. The dollar appreciated further until March 1985, to a total (U.S. trade-weighted) appreciation of about 50% since 1980, partly as a consequence of the monetary-fiscal mix of policies adopted in the United States and abroad. By year-end the dollar had receded from its peak to a point 28% above its 1980 value, as monetary policy eased and fiscal policy tightened marginally.

High U.S. interest rates, the worldwide recession of 1982, and the strong dollar were major contributing factors to the debt crisis in developing countries (and among U.S. farmers). The strong dollar meant weakened dollar prices for many commodities in the world market. Yet most of the external debt was denominated in dollars, so, while high interest rates increased debt-service requirements, the recession and the strong dollar weakened export earnings of many countries and made it more difficult to service the debt.

Once the United States began its rapid recovery, the strong dollar reinforced growing U.S. demand for imports and that, by itself, eased the debt-servicing burden of many countries and also spread the U.S. recovery to the rest of the world. During 1983 and part of 1984, the U.S. economy was the major source of economic growth in the world.

During this period of economic growth, the United States experienced a sharp drop in the rate of inflation from more than 12% in 1980 (heavily influenced by oil price increases) to less than 4% in 1985. Some of this drop was due to the disciplining effect of high unemployment and excess productive capacity on wages and prices during the period, but perhaps half of the drop was due to the sharp appreciation of the dollar. To the extent that the strong dollar has led to an unsustainably large trade deficit, a portion of these inflation gains were "borrowed from the future," so to speak, and will have to be repaid as the dollar depreciates.

In the meantime, the United States reduced its own foreign assets and incurred new debts to the rest of the world by about $270 billion between 1982 and 1985, and a further $300 billion to $400 billion will probably be added before external balance is restored. As a result, the United States will have smaller net earnings on its foreign investments in the future and will require a larger trade surplus to compensate for the decline in net foreign earnings.

Much of this development was foreseeable, but little of it was in fact foreseen. The framework outlined above helps in the interpretation of recent events, but it still falls short of being able to forecast with confidence the detailed consequences of changes in policy in the open U.S. economy.

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and P. B. Kenen, Eds. (Elsevier, Amsterdam, 1985), vol. 2, pp. 859–916]. For a model with rational expectations, see M. Obstfeld ["Floating exchange rates: Experience and prospects," *Brookings Papers in Economic Activity*, no. 2 (Brookings Institution, Washington, DC, 1985)].

5. In technical terms, the set of (linear) differential equations used to describe the movements of the exchange rate and other economic variables has a saddle point solution, whereby one path to equilibrium is stable while the others are not. In forward-looking markets the exchange rate will jump onto the stable path. This process gives rise to the exchange rate "overshooting" its new long-run equilibrium value in order to maintain momentary equilibrium by compensating for the sluggishness or inflexibility of other prices in the economy. This phenomenon illustrates Le Chatelier's principle in physics as applied to an economic system. In Fig. 2, the cumulative surplus achieved between t_0 and t_1 will result in new claims on the rest of the world, hence new earnings on those claims. To restore a situation in which net claims are no longer changing therefore requires some appreciation of the home currency in real terms, for example, a trade deficit offset by the net earnings from abroad. Thus in the long run, the e schedule drops below the P schedule (Fig. 2).
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9. J. Frankel, in *How Open is the U.S. Economy?*, R. W. Hafer, Ed. (Lexington Books, Lexington, MA, 1986), pp. 33–67.
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11. The slope of the GG schedule would be altered by a move from a closed to an open economy, with the GG schedule becoming steeper because some part of any additional expenditure will be used for the purchase of imports and thus will not increase domestic output.
12. The ratio of imports to the U.S. gross national product has more than doubled since the mid-1960's. The share of foreign ownership of securities in the United States and the ratio of foreign to total loans by U.S. banks have roughly trebled. See R. Cooper, in *How Open is the U.S. Economy?*, R. W. Hafer, Ed. (Lexington Books, Lexington, MA, 1986), pp. 3–24.

Molecular Transformations on Single Crystal Metal Surfaces

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One of the primary objectives of modern surface chemistry of transition metals is the synthesis of surface compounds and complexes and the understanding of their reactivity, structure, and bonding. Such considerations are paramount for advancing understanding of catalysis, adhesion, organic thin-film growth, and electrocatalysis. On selected metals, particularly copper, silver, and gold, selective scission of X–H bonds (where X is oxygen, carbon, nitrogen, or sulfur) by surface-bound atomic oxygen occurs to form moderately stable species that can be isolated for further study. Selective oxidation reactions may occur heterogeneously by means of this novel oxygen-activated route. Furthermore, this selective chemistry offers a paradigm for synthesis of a wide variety of surface organometallic complexes, whose formation can be predicted from acid-base principles. These subjects are discussed in this article with emphasis on their role in catalytic oxidation cycles.

IDEALLY, A CHEMICAL CATALYST OR CATALYTIC AGENT increases the rate of a chemical reaction without itself being consumed in the reaction. For example, without chemical intervention carbon monoxide (CO) and nitric oxide (NO), formed in the combustion process, exhaust from an automobile without reacting further and contribute to atmospheric pollution. In the presence of a catalytic converter, these gases react to form harmless carbon dioxide (CO_2) and N_2. The relative rate at which a reaction transpires on a given catalyst is known as the catalyst activity; the degree to which the catalyst directs the course of the chemical conversion toward one product is known as its selectivity. Normally, one desires a maximum rate along with a high selectivity, since this combination maximizes production. For specialty products, however, selectivity considerations may dominate.

Often, catalytic materials interact with the reactant molecules to form intermediate compounds or complexes that undergo further reaction easily. For example, in the conversion of N_2 and H_2 to ammonia (NH_3), if the catalyst is to be of any utility, it must provide a more facile path than that available in the gas phase. This conversion is accomplished catalytically by N–N and H–H bond scission on the surface of the metal catalyst to produce atoms of nitrogen and hydrogen bound to the metal (*1*). A reaction sequence then occurs on the surface with energetic barriers for each step that are lower than the barrier would be in the absence of the catalyst.

This mechanistic principle of catalysis also applies to complex cycles of reactions in living systems (*2*). However, even for simple reaction schemes, a number of reaction paths can be accessible to the reactants; the selective formation of a single product depends on the relative rates of the possible reaction channels. Thus, an understanding of the kinetics of these conversions is important for progress in the field, and manipulation of the state of the surface may enhance or suppress certain reactions. Furthermore, specific identification of the intermediates formed and a detailed understanding of the available reaction channels is crucial. It may be possible to guide the reaction in more desirable directions by intercepting it at specific stages. The methods of surface science offer the opportunity to dissect such processes on the molecular scale and to predict reaction

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