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Robert W. Dimand & Bradley W. Bateman

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John Maynard Keynes Narrates the Great Depression: His Reports to the Philips Electronics Firm†

Robert W. Dimand and Bradley W. Bateman

ABSTRACT
In October 1929, the Dutch electronics firm Philips approached John Maynatd Keynes to write confidential reports on the state of the British and world economies, which he did from January 1930 to November 1934, at first monthly and then quarterly. These substantial reports (Keynes's November 1931 report was twelve typed pages) show Keynes narrating the Great Depression in real time, as the world went through the US slowdown after the Wall Street crash, the Credit-Anstalt collapse in Austria, the German banking crisis (summer 1931), Britain's departure from the gold exchange standard in August and September 1931, the US banking crisis leading to the Bank Holiday of March 1933, the London Economic Conference of 1933, and the coming of the New Deal. This series of reports has not been discussed in the literature, though the reports and surrounding correspondence are in the Chadwyck-Healey microfilm edition of the Keynes Papers. We examine Keynes's account of the unfolding events of the early 1930s, his insistence that the crisis would be more severe and long-lasting than most observers predicted, and his changing position on whether monetary policy would be sufficient to promote recovery and relate his reading of contemporary events to his theoretical development.

Introduction

On October 23, 1929, just as Wall Street began to crash[1] and the world economy moved into exceptionally interesting times, Dr. H. F. van Walsem, counsel and secretary to the Dutch electronics firm N. V. Philips Gloeilampenfabrieken[2], wrote to "J. M. Keynes, Esq., C.B. Cambridge" asking him to write a monthly letter to the firm's Economic Intelligence Service about the state of the British economy and the world economy. John Maynard Keynes's letters to Philips, monthly from January 1930 to November 1931 and then, because of budget cuts to Philips's Economic Intelligence Service, quarterly from February 1932 to November 1934, show Keynes narrating the events of the Great Depression as they occurred, and reveal his perception of the convulsions of the

CONTACT Robert W. Dimand rdimand@brocku.ca, robert.dimand@yale.edu Department of Economics, Brock University, St. Catharines, Ontario L2S 3A1, Canada.

(Fall 2023: Visiting Professor of Economics, Yale University)
Robert W. Dimand is a professor of economics at Brock University, Canada, and a visiting professor at Yale University, and author of *The Origins of the Keynesian* and an editor of *The Elgar Companion to John Maynard Keynes*.
Bradley W. Bateman is president emeritus of Randolph College, Virginia, coauthor of *Capitalist Revolutionary: John Maynard Keynes* and an editor of *The Cambridge Companion to Keynes*.

world economy as he wrote his *General Theory of Employment, Interest and Money* (1936). This substantial body of Keynes's commentary on economic fluctuations (the November 1931 letter alone is twelve typed, double-spaced pages) has hitherto been neglected in the literature on Keynes. Keynes's reports and the associated correspondence, preserved in the Keynes Papers at King's College, Cambridge, are included in the 1993 Chadwyck-Healey microfilm edition of the Keynes Papers (section BM/5 Memoranda Exchanged with Business Houses), but the expense of this edition (which was sold only as a complete set of 170 reels of microfilm, priced at £9,700 or $17,000, plus $175 for a hardcover catalogue, Cox 1993) meant that only a few copies were sold. According to the WorldCat catalogue, there are five sets in libraries in the United States (Library of Congress, Harvard, Yale, Ohio State, and University of Texas at El Paso), two in Great Britain (Universities of Oxford and Sheffield), one in Canada (Victoria University in the University of Toronto) and a few in Germany (Göttingen), Italy and elsewhere but surprisingly little use has been made even of these copies of Keynes's letters to N. V. Philips. Neither Moggridge (1992) nor Skidelsky (1983–2000, 2003), major biographies of Keynes by the authors who know the Keynes Papers best, mentions Keynes's reports to Philips (but Backhouse and Bateman 2011, 129, have a paragraph about Keynes's July 1930 report). As Jacqueline Cox (1995, 171) notes, the thirty volumes of Keynes's *Collected Writings* (1971–1989) include "only a third of the bulk classified as economic" in the Keynes Papers at King's and do not include Keynes's philosophical papers there, while "the personal papers were barely touched." Donald Moggridge (2006, 136–137) observes that "There has, inevitably, been heavier use of the Keynes Papers in King's College Cambridge, which have the advantage of being available elsewhere on microfilm, than, say, his papers in the National Archives or his correspondence with his publishers, the last of which reveals the risks of depending on the Cambridge collection alone." A vast amount of research has been done about Keynes and his economics, yet not all the relevant material has been explored (see Backhouse and Bateman 2006, Dimand and Hagemann 2019).

These reports reveal Keynes's reading of what was happening in the British and world economies through the first four years of the Great Depression, and provide the empirical counterpart to the record of Keynes's theoretical development in this period given by notes taken by students at Keynes's lectures from 1932 to 1935 (Rymes 1987, 1989, Dimand 1988, Dimand and Hagemann 2019). After the success of *The Economic Consequences of the Peace* (1919), Keynes no longer needed to be paid for lecturing, and so gave a single series of eight lectures each year, on the subject of whatever book he was writing at the time, so his lectures from 1932 to 1935 are in effect annual drafts of the book that became *The General Theory*. These lectures at Cambridge and the reports to N. V. Philips on what was happening in the economy provide theoretical and empirical supplements to Keynes's *Collected Writings* (1971–1989), respectively, in following Keynes's intellectual development in the Great Depression, from *A Treatise on Money* (1930) to *The General Theory* (1936). In Keynes's workload, his reports to Philips from 1930 to 1934 took the place of the London and Cambridge Economics Service Special Memoranda on commodity markets that he wrote from 1923 to 1930 (Keynes [1923–30] 1983, 267–647), which provided an empirical counterpart to his normal backwardation theory of futures contracts ([1923] 1983, 1930, Chapter 29).

Replying on October 31 to von Walsem's letter inviting him to write the monthly letter to the firm's Economic Intelligence Service, Keynes was "quite ready to discuss this proposal with one of your representatives" but wished to clarify "that there will be no question of the publication of the letters and that they will be purely for the information of your own people" – and that "it would not be practicable to me to undertake such work except in return for a somewhat substantial fee which might be higher than you would be willing to offer." On November 4, von Walsem assured him that the letters would not be published and "There are only two persons who, though not in our service, are closely related to our firm, who also receive a copy of our Intelligence Service which they, however, are bound to consider as absolutely confidential." He suggested £100 a year. On November 13, Keynes, having "considered your kind proposal in relation to the fees which I have received on previous occasions for somewhat analogous work," offered to undertake the task for an initial six months, for £150 a year[3]. Although Van Walsem had initially asked for the suggestion of other authors if Keynes preferred not take on the task at the suggested £100 a year, and Keynes equally pointedly offered to suggest such alternative authors if Philips did not care to pay £150 a year, Van Walsem accepted Keynes's terms for Philips on November 22: "We think it desirable that one of our gentlemen will see you in order to discuss some details in the first half of December next."

In the event two representatives of Philips (Messrs. Sannes and du Pré) met with Keynes for a discussion summarized "for good order's sake" by van Walsem on December 21, 1929 (by which time van Walsem had already received a December 18 note by Keynes on the Australian exchange position). He recorded agreement that Keynes's monthly letter would treat "some important factor in the development of the British economic situation and give your opinion as to its effects on trade in general and on our business in particular. Also you will draw our attention to important events in the domains especially interesting us, in so far as these come to your knowledge … Whenever you think it necessary you will give us your views on the situation in different parts of the British Empire or eventually of other countries. If possible we shall suggest [to] you special points to be considered in your letters." Von Walsem wrote again on June 21, 1930 to confirm "that the arrangement has given us full satisfaction so that we are willing to continue on the same terms" and enclosed a cheque for 75 pounds. The arrangement also satisfied Keynes; he wrote on January 1, 1931, that "I have enjoyed preparing the letters." Keynes's letters balanced opinions about trade in general with observations about matters affecting Philips more specifically. Thus on January 11, 1930, Keynes stated that "The Factory capacity for Radio Sets seems to have become quite appalling during 1929" before proceeding more generally "to take this opportunity of emphasizing the anxiety which is felt here about the Australian position … I think that Australia may have more difficulties with her balance of trade during the coming year than the Argentine."[4]

The Slump of 1930: Investment, Debts and Deflation

Keynes's April 1930 letter suggested that, although a general improvement had not yet arrived, "there are a fair number of indications that we may be somewhere in the neighborhood of the bottom point." In particular, "the continuance of cheap money, and even more the expectation of such continuance, is bound to be effective in the situation in the course of a few months," but the effect on employment would be slower than on business feeling and the Stock Exchange and "it would not be surprising to see British unemployment figures go on mounting even to the neighborhood of 2,000,000 up to the end of this calendar year. … The effect of many rationalization schemes now in train will be for some time to come to improve profits rather than employment." With a large amount of Australian gold en route to the Bank of England, "there is less anxiety about the British exchange position than there has been for a very considerable time past" and Keynes expected the creation of the Bank for International Settlements to have a positive effect on confidence, a foreshadowing of his emphasis at Bretton Woods on the importance of designing appropriate international monetary institutions. Keynes doubted that the Federal Reserve Board would reverse its cheap money policy "until business and employment in the United States is a great deal better than it is now." This emphasis on expectations would be characteristic of Keynes's *General Theory* (although equally in line with Irving Fisher's quantity theoretic concern with expected inflation), as is the measurement of the ease of monetary policy by the cheapness of money, that is, by low nominal interest rates. Because nominal interest rates (especially short-term rates such as the Treasury Bill rate) were very low in a period of deflation, the Federal Reserve Board continued to view monetary conditions as easy throughout what Milton Friedman and Anna Schwartz (1963) later termed the "Great Contraction" of the US money supply (during which the monetary base increased, but not by enough to offset the rise in currency/deposit and reserve/deposit ratios), despite Fisher drawing the attention of his former student, Federal Reserve Governor Eugene Meyer, to the statistics on the shrinkage of the money supply, the sum of currency and demand deposits (Cargill 1992, Dimand 2019).

On June 24, 1930, H. du Pré emphasized that, "In reply to your remarks about the character of your monthly letters, we assure you that we leave it entirely to you to judge in each case which are the topics which are most worth being discussed by you." Nonetheless, "There is one question upon which we particularly should like to have your opinion." Keynes's monthly letters had repeatedly stated that recovery depended on the bond market becoming more active, with new loans being used not just for the refunding of floating debt but for new productive investment. "But on the other hand these last months many articles in the economic press" saw excessive capacity in many industries; "in other words that the world has first to grow into a productive apparatus which is too big for immediate needs. If this should be true, can a renewed investment-activity soon be hoped for, and if it soon comes, would it really do good? Of course there would be less unemployment in a number of industries; but would not prices of consumptive commodities, and so cost of living, rise? And especially it might turn out after some time, that the new activity has only added to the – supposed – actual over-investment, so that the disequilibrium would only be greater. It may of course be that entirely new industries are going to take the lead, but we do not yet see any that are very likely to do so. We should be much obliged if you would solve this puzzle for us or at least give your views on the pretended overcapacity and its probable effects on future developments in your next letter." This letter sheds light on the audience for Keynes's reports in the secretariat of N. V. Philips: not just salesmen looking for tips about the market for radio sets in Great Britain or elsewhere, but thoughtful businessmen pondering sophisticated economic issues such as the dual nature of productive investment in creating demand while increasing capacity (a problem to which the warranted growth rate of Harrod 1939 was an attempted solution).

In his July 1930 letter (seven typed pages, plus a six-page note on the bond market), Keynes warned that "it is now fully clear the world is in the middle of an international cyclical depression of unusual severity … a depression and a crisis of major dimensions … I believe that the prevailing opinion in the United States is still not pessimistic enough and is relying too much on a recovery in the early autumn, an event which is, in my opinion, most improbable. Nothing is more difficult than to predict the date of recovery. But all previous experience would show that a depression on this scale is not something from which the recovery comes suddenly or quickly." He felt that "The optimism of Wall Street and the hoarding tendencies of France may prevent any real recovery of the International Loan Market this year" and considered whether this might lead to "a psychological atmosphere in which really drastic scientific measures will be taken by Great Britain and the United States in conjunction to do what is humanly possible to cause a turn of the tide next spring. But one is traveling here into the realm of the altogether uncertain and unpredictable." In contrast, the Harvard Economic Society (founded by Harvard economics professors Charles J. Bullock and Warren Persons) stated in its weekly letter on June 28, 1930, that "irregular and conflicting movements of business should soon give way to sustained recovery" and on July 19 that "untoward elements have operated to delay recovery but the evidence nevertheless points to substantial improvement" (quoted by Galbraith 1961, 150, see also Walter Friedman 2014).

Responding to du Pré's query, Keynes reiterated that recovery would be preceded by "a substantial fall in the long-period rate of interest … leading in due course to the recovery of investment." But now he explained that he was not thinking of investment in manufacturing industry, "the world's capacity for which is probably quite ample for the present." Even at the highest estimate, the total cost of bringing Britain's industrial plant up to date "would not use up the country's savings for more than, say, three months. Moreover, when expected profits are satisfactory the rate of expenditure by manufacturing industry in fixed plant is not very sensitive to the rate of interest."

"On the other hand," in contrast to manufacturing, "the borrowing requirements for building, transport and public utilities are not only on a far greater scale, but are decidedly sensitive to the rate of interest. If I were to put my finger on the prime trouble to-day, I should call attention to the very high rate of interest for long-term borrowers … the long-term rate of interest is higher to-day than it has been in time of peace for a very long time past. When, at the same time, there is a big business depression and prices are falling, it is not surprising that new enterprise is kept back at the present level of interest." He drew attention to "those who might be called distress borrowers, that is say countries which have an urgent need for borrowing to pay off existing debts, and are consequently ready to pay a very high rate of interest," citing prospective Austrian, Hungarian and Australian loans on the London bond market, and remarked that "the effect of the German Loan has been to supply the French Treasury with funds, which it has withdrawn from the French market and is keeping unemployed in the

Bank of France." Keynes's July 1930 letter (discussed briefly by Backhouse and Bateman 2011, 129) illuminates both his analysis of the present situation and the role of investment in his economics. His distinction between investment in manufacturing, responsive to expected profit rather than interest rates, and interest-sensitive investment in construction, transport and public utilities clarifies his theory of investment. Increased investment was crucial for recovery of the world economy, and low long-term interest rates were necessary for high levels of investment in construction, transport and public utilities, the largest part of investment (even if manufacturing investment depended more on expected profits). In regard to the current situation, Keynes explained the forces getting long-term interest rates high even when prices were falling and short-term interest rates were low, but felt that "progress has been made toward getting the necessitous borrowers out of the way." On the immediate practical level, Keynes's distinction between the determinants of the two categories of investment dealt with du Pré's question of how low long-term interest rates could stimulate investment given excess productive capacity in manufacturing. And yet, unlike Harrod (1939), Keynes's July 1930 letter did not come to grips with the theoretical point raised by du Pré, the dual character of investment in creating both demand and productive capacity.

Keynes's August 1930 letter dissented from the view widely held in the United States "even in responsible quarters, that we may expect an autumn recovery with some confidence … a good deal of the American optimism is based on analogies drawn from the date of recovery after the 1920-21 slump" (compare the Harvard Economic Society's statement on August 30 that "the present depression has about spent its force," quoted by Galbraith 1961, 150). He argued that "Too much emphasis cannot be laid on the really catastrophic character of the price falls of some of the principal raw materials since a year ago" (even larger than appeared from published index numbers, because those included a number of commodities subject to price controls), which "must profoundly affect the purchasing power of all overseas markets." Long-term interest rates remained high, reducing new capital investment. In contrast, Keynes considered general opinion about the British position to be "perhaps a little too pessimistic." Britain was already in a difficult position before the slump of 1929 and 1930, because of the 1925 return to the gold exchange standard at the prewar parity (over the eloquent protests of Keynes 1925). But the heavy unemployment in the slump was limited to textiles and heavy industry (iron and steel, coal, and shipbuilding), export-based sectors already hit by the return to gold at an overvalued exchange rate (in his December 1930 letter, Keynes stated that if textiles, iron and steel, and coal were omitted, there was practically no decline in the Index of Production from a year before and an improvement from two years before). Keynes explained that British unemployment statistics, when used in international comparisons, "probably overstate the case" since the British statistics included "a great many workers in definite employment, but working short time … It is even the case that workers taking their normal summer holidays are now included in the figures of the unemployed." According to *The Economist*, the aggregate profits of all British joint stock companies reporting their earnings in the first half of 1930 "were not only greater than in the previous year, but were larger than in any previous year. This was partly due to the prosperity of British Oil Companies operating abroad, but by no means wholly." Nor did Keynes share the worries of financial opinion in London (and so some extent his own previous letter to Philips) about "the constant dribble of gold to France."

In Keynes's September 1930 letter to Philips, he was "still of the opinion that real recovery is a long way off. But at the same time it seems to me not unlikely that we are at, or near, the lowest point … It is time, therefore, to cease to be a 'bear', even if it is not yet time to be a 'bull'." His February 1931 letter began, "Glancing through the letters of previous months, I find that they were all extremely pessimistic (with a brief lapse into modified optimism in September, corrected in October). Nevertheless, in the light of the actual course of events they were scarcely pessimistic enough. Nor do I see any reason for expecting any appreciable alleviation in the coming months." His September 1930 letter reported that "An extraordinary example of the way in which a situation can suddenly turn round, when a tendency has been greatly overdone, has been seen on the London Stock Exchange in the last two weeks. There has been no recovery of business in Great Britain to account for it. The real facts are much as they were a month ago. But market pessimism, aided by bear operations, had brought security prices down to an absurdly low level not justified by the circumstances … everyone knew in his heart that prices were falling to foolish levels. The result was that within a few days the prices of many leading securities had risen from 10 to 20 per cent." The stock market had diverged from any level that could be construed as reflecting underlying fundamentals, but then abruptly bounced back. Keynes again stressed that Britain was not doing as badly as the United States in the slump: the fall in the British index of production from the previous year "is certainly less than 10 per cent" whereas the US index of industrial production for July 1930 was 37% below that for July 1929.

Keynes's 1930 "October Letter" warned that, "The catastrophic increase in the value of money has raised the burden of indebtedness of many countries beyond what they can bear … in many parts of the world the fall of prices has now reached a point where it is straining the social system at its foundations. Agriculturists and other producers of primary materials are being threatened with ruin and bankruptcy all over the world. It is useless to expect a recovery of markets in such conditions" (and in his February 1931 letter he again warned that "The prospect of a long series of defaults [by debtor countries exporting raw materials] during 1931 is not be excluded"). All of the gains that Germany had received in the Young Plan for reparations compared to the Dawes Plan were obliterated because "the clause in the Dawes Plan by which her [Germany's] liabilities in terms of gold were to be modified in the event of a change in prices was not included in the Young Plan." Keynes declared himself "rather more pessimistic … than a month ago." He remarked that in Britain, "Very slight steps have been taken, as yet, in the direction of reducing wages, which is probably inevitable, but will not get anyone much further if all countries alike embark on wage-cutting policies."

These themes of Keynes's October 1930 letter to Philips, the danger of ruin and bankruptcy from price deflation in a world where debts are fixed in money terms and the futility of wage-cutting, appeared publically in his December article in *The Nation and Atheneum* on "The Great Slump of 1930" (reprinted in his *Essays in Persuasion*, 1931). There Keynes (1931, 138–139) warned that, since wage and price deflation increases the real burden of debt and wage cuts reduce purchasing power, "neither the restriction of output nor the reduction of wages serves in itself to restore equilibrium" and went on to emphasize that "Moreover, even if we were to succeed eventually in reestablishing output at the lower level of money-wages appropriate to (say) the pre-war level of prices, our troubles would not be at an end. For since 1914 an immense burden of bonded debt, both national and international, has been contracted, which is fixed in terms of money. Thus every fall of prices increases the value of the money in which it is fixed. For example, if we were to settle down to the pre-war level of prices, the British National Debt would be nearly 40% greater than it was in 1924 and double what it was in 1920; … the obligations of such debtor countries as those of South America and Australia would become insupportable without a reduction of their standard of life for the benefit of their creditors; agriculturalists and householders throughout the world, who have borrowed o mortgage, would find themselves the victims of their creditors. In such a situation it must be doubtful whether the necessary adjustments could be made in time to prevent a series of bankruptcies, defaults, and repudiations which would shake the capitalist order to its foundations" (see also Dimand 2011). Here, before Fisher (1932, 1933, see Dimand 2019), was the concern with the effect of deflation on the real value of nominal deflation that reappeared in Chapter 19, "Changes in Money Wages," of *The General Theory*, where Keynes (1936, 264) warned that "if the fall of wages and prices goes far, the embarrassment of those entrepreneurs who are heavily indebted may soon reach the point of insolvency – with severely adverse effects on investment."

Contested Budgets, Trade Balance and the Banking and Exchange Crises of 1931

In 1930, Keynes's "November Letter" argued that foreign opinion underestimated the financial strength that accompanied Britain's industrial weakness: "it is forgotten that the adverse tendencies of the foreign exchanges, until recently, have been due, not to the absence of a favorable foreign trade balance, but to the eagerness of British investors to take advantage of the high profits or high rates of interest obtainable abroad. In 1929 the British favorable balance available for new foreign investment was greater than that for any other country, greater even than that for the United States. The Bank of England's difficulties were due to the fact that the pressure of savers to take advantage of opportunities abroad was even greater." Subsequent events in Wall Street and elsewhere had made overseas investment less appealing to British savers, so that the Bank of England was holding twenty million pounds sterling more of gold than a year before. In his December 1930 letter, Keynes reported that, even though "The perpetual drain of gold to France provides a source of nervousness and irritation in the money market" and although thirty million pounds sterling of gold had moved from Britain to France in the previous three months, the Bank of England held twenty-two million pounds sterling more in gold than a year before (but Keynes's March 1931 letter reported that a drain of twenty million pounds sterling of gold from the Bank of England in the previous three months "causing nervous talk to prevail in London"). Despite Keynes's repeated insistence on the financial strength of sterling and the growing gold reserves of the Bank of England (less than a year before the crisis of August and September 1931 that forced Britain off the gold exchange standard), the underlying message was that capital mobility under fixed exchange rates would constrain even the Bank of England from trying to lower long-term interest rates to stimulate investment. Until Britain left the gold standard and allowed sterling to float, Keynes's letters to Philips monitored the strength of protectionist sentiment in the British Government, but he lost interest in tariff proposals once the exchange rate was no longer pegged (see Keynes 1931). But there was one bright spot for Britain: Keynes's February 1931 letter stressed that "It must not be overlooked that England is gaining enormously by the tremendous drop in the price of her imports as compared with that of her exports."

Keynes's April 1931 letter to Philips is notable for explaining that Britain's apparent budget deficit of £23.5 million for the fiscal year ending March 31 "is not as bad as it sounds, since this figure is reached after allowing for the repayment of £67,000,000 of debt. So that, apart from debt repayments, there was a surplus on the year's workings of £43,500,000. It must be doubtful whether any other country is showing so favorable a result. Even if the sum borrowed for the unemployment fund, which lies outside the budget[5], were to be deducted, there would still have on the year a net reduction of debt." The next year's was expected to be larger, but "If no debt were to be repaid, there would probably be no deficit, even for the forthcoming year." Keynes's May 1931 letter, reporting on the budget presented by Labor Chancellor of the Exchequer Phillip Snowden, noted that "there will still be some reduction of debt during the forthcoming year, though not on as large as a scale as formerly." A few months later, when Snowden and Prime Minister Ramsay MacDonald broke with their party to join the Conservatives in a National Government to deal with a budget and exchange crisis, Snowden found it convenient to overlook that the apparent budget deficit was an artifact of budgeting for a reduction in the national debt, and to denounce his former Labor Cabinet colleagues for endangering the savings of small depositors by having the Post Office Savings Bank lend to the Unemployment Insurance Fund, without mentioned that such loans were guaranteed by the Treasury or that he had neglected to inform his Cabinet colleagues of the borrowing (as Keynes indignantly explained in two paragraphs in the draft of his November 1931 letter, deleted from the final version).

Keynes's May 1931 letter is also notable, in light of the subsequent exchange crisis that forced Britain off gold in September, for insisting that "The improvement in the sterling exchanges and the better gold position of the Bank of England, as it appears in the public returns, are not deceptive and may be assessed at even more than their face value." He held that "When there is no longer serious pressure on the Bank of England's gold, the stage will be set for really cheap money throughout the world … It will not mean a recovery, but it will pave the way for the recovery of investment which must precede the recovery of prices and profits." Keynes again emphasized that "the fall in the prices of the commodities imported by Great Britain has been so much greater than the fall in the prices of her exports. On the visible trade balance Great Britain was £5,000,000 better off in the first quarter of 1931 than in either of the preceding years … Thus the main burden of the present crisis falls on the raw-material-producing countries, and Great Britain is likely to gain gold in spite of the immense decline of her exports."

By the next month, as the Credit-Anstalt collapsed in Vienna (see Schubert 1991), as French and American capital then took flight from Germany (see Balderston 1994), and as share prices slumped in London, Wall Street and on most European bourses, Keynes felt "that we are now entering the crisis, or panic, phase of the slump. I am inclined to think that we look back on this particular slump we shall feel that this phase has been reached in the summer months of 1931, rather than at any earlier date." He warned that "the consequences of a change in the value of money, as reflected in the prices of leading commodities, so violent as that which has occurred in the last eighteen months, cannot be regarded too gravely. Until prices show a material rise the whole fabric of economic society will be shaken. Each decline of commodity prices and each further collapse on the Stock Exchanges of the world brings a further group of individuals or institutions into a position where their assets doubtfully exceed their liabilities."

Looking across the Atlantic: The American Slump

Keynes's July 1931 letter focused on the United States, where 21% of the industrial population was unemployed with perhaps another 20% working only two or three days a week: "it is quite out of the question that there should be anything which could be called a true recovery of trade at any time within, say, the next nine months. The necessary foundations for such a recover simply do not exist." Many of the loans of small banks to farmers or secured by real estate "are non-liquid and probably impaired. Thus there is a strong desire for the utmost liquidity while obtainable on the part of the ordinary Bank; and general unwillingness to take any unnecessary risks or to embark on speculative enterprise, even where the risk may be actuarially a sound one. The nervousness on the part of the Bankers is accompanied by a nervousness of the part of their depositors … So there is quite a common tendency to withdraw money from the banks and keep resources hoarded in actual cash … It was estimated that in the country as a whole as much as $500,000,000 was hoarded in actual cash in this way" (see Fisher 1933, Friedman and Schwartz 1963, Bernanke 2000). Keynes stressed that, "The American financial structure is more able than the financial structure of the European countries to support the strain of so great a change in the value of money. The very great development of Bank deposit and of bondage indebtedness in the United States means that a money contract has been interposed between the real estate on the one hand and the ultimate owner of the wealth on the other. The depreciation in the money value of the real estate sufficient to cause margins to run off, necessarily tends therefore to threaten the solidity of the structure."

Keynes reported in his July 1931 letter that although US agricultural wages had fallen by 20 to 25%, and there had also been large cuts to wages in small-scale industrial enterprises, hourly wages were practically unchanged for two thirds of the workers in large-scale industrial enterprises while the hourly wages of the other third had been reduced by some 10%. In October 1934, however, Keynes stated in his Cambridge lectures that "Labor will and has accepted reductions in money wages, in the USA in 1932, and it will not serve to reduce unemployment" with one student's notes calling the money-wage reductions "catastrophic" (Rymes 1987, 131).

Germany Defaults, Britain Abandons the Gold Parity

Turning from the United States, Keynes remarked near the end of his July letter that, "At the moment of writing there are heavy gold drains from London; but I do not think that this need be regarded with any undue alarm," a judgment that proved too sanguine.

More presciently, he added "The real danger in the situation comes from the possibility of the declaration of a general moratorium in Germany and the collapse of the mark [Germany defaulted on July 15]. The repercussion of such events on the solvency of the banking and money market systems of the world would be most serious." The next month, in his August 1931 newsletter (dated August 4), Keynes reported that "the bulk of the remaining short-term German debt is due to British and American banks and accepting houses; many accepting houses being landed with what are certainly frozen and may prove doubtful debts. Their own credit has suffered with the inevitable result, since they were the holders of large foreign balances, of a drain of gold from London … it would seem to be only ordinary prudence to act on the assumption that, while worse developments in Germany are doubtless possible, even apart from this the general underlying position is worse than the ordinary reader of newspapers believes it to be." While "Great Britain is suffering from the temporary shock to confidence due to the difficulties of the accepting houses,"[6] the situation of the world economy as a whole was more serious: "We are certainly standing in the midst of the greatest economic crisis of the modern world. Important though the German developments have been I would emphasize that these have been essentially consequences of deeper causes which are affecting all countries alike … For there is no financial structure which can withstand the strain of so violent a disturbance of values." A handwritten postscript at the end of the typed August 1931 letter warns Keynes's readers "not to be encouraged even by the appearance of apparently good news. The world financial structure is shaken and is rotten in many directions. Patching arrangements will be attempted, but they will not do much good, and it would be a mistake to place reliance on them." The next day, August 5, Keynes, writing to Prime Minister J. Ramsay MacDonald to urge rejection of the May Report, stated that "it is now virtually *certain* that we shall go off the existing parity at no distant date … when doubts, as to the prosperity of a currency, such as now exist about sterling, have come into existence, the game's up" (Keynes 1971–1989, Vol. XX, 591–593; Skidelsky 2003, 446), but he did not say so in print or to Philips – and he rejected, on patriotic grounds, a suggestion by O. T. Falk that the Independent Investment Trust, of which Keynes and Falk were directors, should replace a dollar loan with a sterling loan, which Keynes condemned as "a frank bear speculation against sterling." The Independent Investment Trust lost £40,000 by not switching its financing (Keynes 1971–1989, Vol. XX, 611–612; Moggridge 1992, 528–529; Skidelsky 2003, 447).

It was not only the world financial structure that was shaken; so was the Secretary Department of N. V. Philips. On August 6, 1931, H. du Pré wrote plaintively to Keynes, "Though we could hardly expect otherwise from your former letters, we note that you are not at all optimistic about the developments in the latter part of this year. These last weeks we read in the papers some statements from several Americans (among them people of authority), which hold a somewhat more cheerful view for the coming months. Must we infer from your letter that they are still, or again, too optimistic or is it possible that since your return from America[7] there have been some improvements, which may lead one to expect some improvement at least for the autumn?" Even Roger Babson, who had made his reputation by being bearish about the stock market in September 1929 (as he had been since 1926), was bullish by early 1931 (see W. Friedman 2014).

Keynes's reply on August 12 crushed any hopes: "In response to your enquiry, nothing has happened to make me more optimistic. As regards America, I consider that recovery this autumn is altogether out of the question. But the minds of all of us are of course dominated by the European and indeed the world situation. This still seems to me to be, as I have already described it, more serious than the general public know. I should recommend as complete inaction as is possible until further crises, or further striking events of some kind or another have occurred to clear up the situation."

Keynes's September letter (dated September 10, 1931), after the Conservative-dominated National Government displaced Labor, warned that "the hysterical concentration on Budgeting economy, which has also spread to the curtailment of expenditure by Local Authorities is calculated to produce unfavorable developments. For the widespread curtailment of expenditure is certain to reduce business profits and increase unemployment and lower the receipts of the Treasury, whilst it will do very little to tackle what is the fundamental problem, namely the improvement of the British Trade Balance. We seem likely to be faced by a period during which the balance of trade will not be sufficient to give confidence to foreign depositors."

It turned out, however, that one part of the cuts in government spending, the reduction in pay of the armed services, did indirectly dispose of the balance of payments problem. Since the government's version of equal sacrifice was that a vice-admiral earning £5 10s a day would lose 10 shillings a day (a reduction of 1/11), while naval lieutenants earning £1 7s a day and able-bodied seamen earning 5 shillings a day should each lose a shilling a day, reductions of 1/27 and 1/5, respectively (Muggeridge 1940, 109n), a naval mutiny erupted at Invergordon on September 16 (the first British naval mutiny since 1797), leading to abandonment of a fixed exchange rate on September 21 and a prompt 20% depreciation of sterling. Once the gold parity was abandoned, interest rates could be lowered without any balance of payments crisis. Commander Stephen King-Hall remarked "the strange combination of circumstances which caused the Royal Navy to be used by a far-seeing Providence as the unconscious means of … releasing the nation from the onerous terms of the contract of 1925 when the pound was restored to gold at pre-war parity … In 1805 the Navy saved the nation at Trafalgar; it may be that at Invergordon it achieved a like feat" (quoted by Muggeridge 1940, 111n). As for the budget deficit, Chancellor Snowden, who in the preceding Labor government had steadfastly blocked any reduction in the Sinking Fund contributions for paying down the national debt, now presented a budget reducing the annual Sinking Fund contribution by £20 million. Keynes declared in his October 1931 letter to Philips, "Great Britain's inevitable departure from the gold standard having occurred, it has been received with almost universal relief and in industrial circles a spirit of optimism is now abroad … Since the City and the Bank of England did their utmost to avoid the change, they feel that honor is satisfied. In other quarters the effect is to relieve a tension which was becoming almost unbearable … I have no doubt at all as to the reality of the stimulus which British business has obtained." Fisher (1935), assembling data on twenty-nine countries, found that recovery began only once a country abandoned the gold parity and was able to pursue a looser monetary policy (see Dimand 2003).

Keynes concluded his October 1931 letter, “The general passion for liquidity is bringing the value of cash in terms of everything else to so high a level as to be very near breaking point. This does not apply to Great Britain since her crisis was a balance of payments crisis rather than a banking crisis strictly so called. Thus the possibility of a general European and American banking crisis is the main risk, the possibility of which has now to be borne in mind.” The US banking crisis culminated in the “Bank Holiday” of March 1933, while all the major German and Italian banks passed into government ownership.

On November 3, 1931, Dr. du Pré was “very sorry to say that the necessity for the strictest economy which makes itself felt in all departments of our concern at present, impels us to an important curtailment of the budget of our Economic Intelligence Service” which would now issue bulletins every three months, instead of monthly. He asked Keynes for quarterly letters for £50 per annum, instead of monthly letters for £150 per annum. Keynes replied on November 9 that he read the letter “without any great surprise. I had been rather hesitating in my mind as to whether it is worth while to continue the arrangement on the new basis. But on the whole I feel that I should not like to break the friendly relations which have arisen between us, merely because times are bad.” He accepted the offer[8], asking to be reminded when each quarterly report was due, and enclosed his November letter stating that Britain was “to a considerable extent getting the best of both worlds since broadly speaking the countries from which we buy our food and raw materials have followed us off gold, whilst our manufacturing competitors have remained on the old gold parity.”[9] He felt that Continental observers were mistaken to think that Britain would want to return to gold: “Foreigners always underestimate the slow infiltration of what I have sometimes called ‘inside opinion’, whilst ‘outside opinion’ remains ostensibly unchanged. Then quite suddenly what ‘inside opinion’ becomes ‘outside opinion’. Foreigners are quite taken by surprise, but the change is really one which had been long prepared. In the later months of the old gold standard there was a hardly a soul in this country who really believed in it. But it was considered that it was our duty for fairly obvious reasons to do everything we possibly could to keep where we were.”

Keynes’s May 1932 quarterly letter stressed that, “The most important development, if one is thinking not so much of the moment but of laying the foundations for future improvement, is to be found in the return to cheap money, which was interrupted by the financial crisis of last summer and the departure from gold. I am more and more convinced in the belief, which I have held for some time, that an ultra-cheap money phase in the principal financial centers is an indispensable preliminary to recovery … Nevertheless it would be imprudent to expect too much at any early date from the stimulus of cheap money. The courage of enterprise is now so completely broken, that the effect on prices of money however cheap will be very slow. I consider it likely, therefore, that the cheap money phase may be extremely prolonged and that it may proceed to unprecedented lengths before it produces its effect.” He concluded, “For the time being the world is marking time, – waiting for it does not quite know what. I emphasize again the fact that the position in Great Britain, and in some of her Dominions, is relatively good. But for the time being, I see no light anywhere else … It would certainly be much too soon to take any steps whatever to be ready for a possible revival.”

Looking across the Atlantic: Hope from the New Deal

Keynes's August 1932 memorandum was notable for its explanation of why US stock prices had risen sharply and why that need not signal an end to the industrial crisis: the financial crisis had driven down stock prices until "the securities of many famous and successful companies were standing at little more than the equivalent of the net cash and liquid resources owned by those companies … the assets in question would either be worth nothing as a result of the general breakdown of contract, or must, in any circumstances apart from that, be worth a very great deal more than their quotations. Consequently, it is logical and right that the fear of their being worth nothing having been brought to an end, there should be a rapid recovery of the quotations on a very striking scale. It does not need a termination of the industrial crisis, or even an expectation of its early cessation, in order to justify the new levels."

In his February 1933 memorandum, commenting on the likely futility of the projected World Economic Conference, Keynes recalled that "I have myself put forward more drastic proposals for an international fiduciary currency, which would be the legal equivalent of gold. If this were agreed to, the position would be so much eased that various other desirable measures would also become practicable. I do not despair of converting British opinion to such a plan, but I am told that continental opinion would be almost unanimously opposed it." Keynes had contemplated such proposals long before Bretton Woods.

Keynes's August 1933 memorandum (actually mailed July 20, before Keynes left for holidays) held that "My own view is that President's Roosevelt's programme is to be taken most seriously as a means not only of American, but of world recovery. He will suffer set-backs and no one can predict the end of the story. But it does seem fairly safe to say that his drastic policies have had the result of turning the tide in the direction of better security not only in the United States, but elsewhere … Perhaps in the end President Roosevelt will devalue the dollar in terms of gold by 30 or 40 per cent." His November 1933 memorandum regretted "the failure of the President during his first six months to act inflation as well as talk it. In actual fact Governmental loan expenditure in the United States up to the end of September was on quite a trifling scale" but since then it seemed to be increasing: "if during the next six months the President is at last successful in putting into circulation a large volume of loan expenditure, I should expect a correspondingly rapid improvement in the industrial prosperity of America. This, if it occurs, would have a great influence on the rest of the world and especially on Great Britain … it might pave the way for a rate of improvement sufficiently rapid to deserve the name of real recovery." Keynes's February 1934 memorandum reported that in the United States "everything is moving strongly upwards. This is to be largely attributed to the fact that Governmental loan expenditure is now at last occurring on a large scale … the disbursement by the American Treasury of new money against borrowing has reached or is approaching $50,000,000 weekly and should maintain this rate for a few months to come." In his August 1934 memorandum, having visited the United States since his May memorandum, he found there "a recession which is somewhat more than seasonal," aggravated since his visit by a "failure of the corn crop … so acute as to be little short of a national disaster" but the actual and prospective level of US Government loan-financed expenditure made him optimistic about prospects for the US economy in the autumn and winter. He also reported that "the view is generally held in Great Britain that the gold block countries – including Holland not less than the others – cannot permanently maintain their present parity with gold without a disaster. Now or later it seems to us certain that the necessity for devaluation will be admitted." The reports end with Keynes's November 1934 memorandum, with no correspondence in the Keynes Papers concerning the end of his relationship with the Philips firm.

Conclusion: The Message of Keynes's Reports to Philips

Keynes's letters to the Philips electronics firm reveal he perceived events in the British and world economies from the beginning of 1930 through November 1934, and provide pungent and insightful commentary. These reports high-light the importance to Keynes of cheap money as a stimulus to investment – he was not just concerned with fiscal policy as the means to recovery, however much he placed emphasis from 1933 onward on the loan-financed expenditure of the Roosevelt Administration in the US. Keynes's response to a query from du Pré is particularly interesting about Keynes's distinction between those investment expenditures that are sensitive to interest rates and those that are not. The reports stress a theme discussed more briefly in Keynes's 1931 Harris Foundation lectures in Chicago (in Wright, ed., 1931) and in Chapter 19 of *The General Theory*, and at greater length by Irving Fisher (1932, 1933) (and later by Hyman Minsky 1975): since debt are contracted in nominal terms, a rise in the purchasing power of money increases the risk of bankruptcy, repudiation and default – and it is not just actual defaults that are costly, but also the perception of increased riskiness. Keynes recognized the exceptional seriousness of the Depression, dissenting firmly from predictions of an early recovery, and he saw clearly how defending overvalued gold parities forced central banks to keep interest rates high, instead of pursuing ultra-cheap money to restore investment. This hitherto-neglected body of evidence allows one to watch the unfolding of the world economic crisis of the early 1930s through Keynes's eyes, extraordinary events as viewed and narrated by an extraordinary economist. At £12 10s per report (by no means a trivial sum at the time), N. V. Philips certainly got their money's worth.

Notes

1. "Thursday, October 24, is the first of the days which history – such as it is on the subject – identifies with the panic of 1929" (Galbraith 1961, 103–104), but already on Monday, October 21, Irving Fisher had characterized the fall in stock prices as just the "shaking out of the lunatic fringe" and on Tuesday, Charles Mitchell of the National City Bank declared that "the decline has gone too far" (Galbraith 1961, 102).
2. Philips Incandescent Lamp Works, later Philips Electronics, successor to a firm founded by Lion Philips (originally Presburg), maternal uncle of Karl Marx (Gabriel 2011, 44, 110, 291-93, 295, 299, 315, 334, 366). Although relations between uncle and nephew were "strained by politics" (Gabriel 2011, 291), Mary Gabriel (2011, 299) refers to Marx's "fund of last resort, his uncle … He had sold himself to this pragmatic businessman as a successful writer only temporarily short of cash." Gabriel (2011, 642) remarks that "Marx's dabbling in the stock market has been questioned by some scholars, who believe he may simply have wanted his uncle to believe he was engaged in 'capital' transactions, not *Capital*." After the death of Lion

Philips, his sons did not reply to Marx's letter asking for help with his daughter Laura's wedding (Gabriel 2011, 364). Anthony Sampson (1968, 95) reported that the firm's chairman Frits Philips was "a keen Moral Rearmer and a fervent anti-communist, embarrassed by the fact that his grandfather was a cousin of Karl Marx."

3. For a sense of what £150 a year might have meant to Keynes: Moggridge (1992, 508, 585) and Skidelsky (2003, 417–418, 519, 565) report that Keynes's net worth fluctuated from £44,000 at the end of 1927 to £7,815 at the end of 1929, then rising to over £506,222 at the end of 1936, dropping again to £181,244 at the end of 1938. The offer from Philips came at a particularly low point in his finances. According to Skidelsky (2003, 265) "investment, directorship and consultancy income" accounted for more than 70% of Keynes's income between 1923-24 and 1928-29 (including £1,000 a year as chairman of National Mutual Life Assurance), books and articles for another 20%, leaving no more than a tenth of income from such academic sources as teaching, examining, being secretary of the Royal Economic Society and editor of its journal, and being Bursar and a Fellow of King's College.
4. However, writing to Keynes on January 21, H. du Pré was moved "to remark that the latest figures from the Argentine which, according to the handwritten note at the bottom of your letter, you intended to enclose, were not received here, so that we cannot give you an opinion about their importance for us."
5. When the majority report of the May Committee on National Expenditure projected on July 31, 1931, that the budget deficit for 1931-32 would be £120 million, necessitating £96 million of cuts to unemployment benefits, road construction, and government and armed forces pay, it counted all borrowing by the Unemployment and Road funds as "public expenditure on current account" as well as "the usual provision for the redemption of debt" of £50 million (Winch 1969, 126–130). Keynes accused the majority on the May Committee of not "having given a moment's thought to the possible repercussions of their programme, either on the volume of unemployment or on the receipts of taxation" – he estimated it would add 250,000 to 400,000 to the unemployed, and reduce tax receipts by £70 million (*New Statesman and Nation*, August 15, 1931; Keynes 1971-89, Vol. IX, 141–145; Winch 1969, 130, Skidelsky 2003, 446).
6. With regard to Britain, Keynes noted that "There is, however, tremendous pressure of public opinion towards the Government Economy, which means in the main a reduction in the salaries of Government employees and of the allowances of the unemployed. It is equally difficult for the present [Labour] Government either to refuse or concede concessions to this trend of opinion. But if a movement in this direction takes place, which is still most doubtful, it remains exceedingly open to argument whether the result on the actual level of unemployment will be favourable."
7. Keynes had given three Harris Foundation Lectures on "An Economic Analysis of Unemployment" at the University of Chicago in June and July 1931, published in Quincy Wright, ed. (1931), and reprinted in Keynes (1971-89), Vol. XIII. These lectures mostly expounded the analysis of Keynes's *Treatise*, but the third lecture also examined the debt-deflation process, the undermining of the financial structure by an increase in the real value of debts and fall in the nominal value of collateral (Keynes 1971-89, Vol. XIII, 359–361, see Dimand 2011).
8. He also raised a "small personal matter", asking for advice on buying a new wireless set that would "have a thoroughly good loud speaker, both for voice and music reproduction and should be able to pick up distant stations such as Moscow."
9. A passage crossed-out in the draft of Keynes's November 1931 letter, in the section discussing the general election, stated that, "As has been the case in the last three or four General Elections, it is that old wretch Lord Rothermere [publisher of the *Daily Mail*] who has been dead right. It is said that he has made a profit on the crisis of £100,000, buying majorities on the Stock Exchange." Skidelsky (2003, 472) relates that Keynes "consistently lost money (his own and his friends') on the results of general elections."

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Foreign Students in College and the Supply of STEM Graduates

Massimo Anelli, *Bocconi University, Institute of Labor Economics (IZA), and CESifo*

Kevin Shih, *Queens College, City University of New York*

Kevin Williams, *Occidental College*

Do foreign students affect the likelihood that domestic students obtain a STEM degree and occupation? Using administrative student records from a US university, we exploit idiosyncratic variation in the share of foreign classmates in introductory math classes and find that foreign classmates displace domestic students from STEM majors and occupations. However, displaced students gravitate toward high-earning social science majors, so their expected earnings are not penalized. We explore several mechanisms. Results indicate that displacement is concentrated in classes where foreign classmates possess weak English language ability, suggesting that diminished in-class communication and social interactions might play an important role.

I. Introduction

Encouraging science, technology, engineering, and mathematics (STEM) education has been a long-standing goal in the United States, as STEM workers are key drivers of innovation and growth (Griliches 1992; Jones 1995; Kerr and Lincoln 2010; Peri, Shih, and Sparber 2015). Higher education

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has been an area of particular concern, as recent decades have seen reductions in the share of degrees awarded in STEM fields and substantial problems with retention—more than 50% of intended STEM majors end up switching to non-STEM fields or dropping out (Chen 2013). Sourcing STEM skills from abroad is one way to assuage concerns over inadequate domestic supply of STEM skills.[1] Large-scale immigration into the workforce has been accompanied by a growing presence of foreign students in higher education as family reunification and less restrictive student visa policies provide pathways for youth immigration.

This paper examines whether the growing presence of foreign students in higher education affects the likelihood that US domestic students complete STEM degrees and eventually work in STEM jobs. We study this in the classroom setting, drawing on administrative student-level records from a large US research university over the 2000–2012 academic years. We focus our analysis on domestic US citizens who attend introductory math courses—often considered an initial gateway for STEM majors—during their first college term. We then explore whether the share of introductory math classmates who are foreign affects the likelihood of graduating with a STEM degree and working in a STEM occupation.

We classify students as foreign if they do not possess US citizenship.[2] The period we analyze precedes the large surge in temporary student visa holders, which began in the late 2000s.[3] As such, our sample of foreign students

as well as seminar participants at the University of Connecticut; Williams College; Brigham Young University; Rensselaer Polytechnic Institute; European University Institute; Stavanger Education and Child Development workshop; Swedish Institute for Social Research (SOFI), Stockholm University; Norwegian School of Economics; University of Texas at Austin; CESifo Area Conference on Employment and Social Protection; Milan Labor Lunch Seminar Annual Workshop; Debenedetti workshop; Tenth International Workshop on Applied Economics of Education, Catanzaro; and the 2017 Association for Education Finance and Policy (AEFP) conference. The views expressed herein are those of the authors alone. Contact the corresponding author, Massimo Anelli, at massimo.anelli@unibocconi.it. Information concerning access to the data used in this paper is available as supplemental material online.

[1] Programs like the H-1B and optional practical training (OPT) visa explicitly aim to select STEM workers.

[2] Domestic US citizens also include a minority of individuals who are born abroad: 7.7% of all US citizens with some college in the cohorts of interest are born abroad and naturalized, according to our own calculation using American Community Survey (ACS) data. However, for the purposes of informing how STEM human capital flows into the labor market, US citizenship is the most relevant margin. Naturalized citizens are more likely to be assimilated to US-born students, and immigration programs place large restrictions on the entry of noncitizens into the US labor market.

[3] Data from Institute of International Education Open Doors reports indicate that international undergraduate enrollment in the United States grew by 73% from 2010 to 2020. The institution we study sustained large-scale growth in international undergraduates from 2% to more than 10% of enrollment over the same decade.

primarily consists of noncitizen permanent residents (87% of all foreign students), and virtually all are in-state residents—88% of foreign students are state residents compared with 97% of domestic students.[4] Importantly, permanent residents are likely to be more assimilated than student visa holders, and the incentives to major in STEM likely differ between the two groups. Additionally, US immigration policy prevents most student visa holders from remaining after graduation—currently only 10% of F-1 student visa holders transition to an H-1B visa, which provides temporary work authorization in the United States (Bound et al. 2021).

Our results show that foreign classmates reduce the likelihood that American students graduate with a STEM major and eventually work in a STEM occupation. A 1 standard deviation (4.4 percentage point) increase in the share of introductory math classmates who are foreign reduces the probability of graduating with a STEM degree and also working in a STEM occupation by 4.7 percentage points, or 10% of the mean STEM graduation rate of 48%. Applying our estimates to an average-sized class indicates that 10 additional foreign classmates displace 6.7 domestic students from STEM degrees/occupations. Local linear regression analysis suggests that the displacement might be more pronounced among domestic students who possess a weak comparative advantage in STEM fields relative to non-STEM fields (rather than an absolute STEM disadvantage). These students then increase their propensity of majoring/working in social science majors/occupations that have equally high earning potential compared with the STEM fields they leave. There is therefore no detectable aggregate impact on the expected earnings of domestic students. Our results imply that the total number of STEM graduates is slightly reduced, by about 2%, as the increased inflow of foreign students into STEM majors does not entirely offset the displacement of domestic students.[5]

[4] Among foreign students, the distribution of permanent residents and student visa holders is roughly similar when separately examining each ethnic/racial group. For each ethnic/racial group (i.e., Asian, White, and minority [Black and Latino]), about 88%–90% are permanent residents while 11%–13% are visa holders. We note that literature has documented that much of the later growth in student visa holders since the late 2000s has been from Asian students, particularly Chinese students (Khanna et al. 2020; Bound et al. 2021). With respect to state residency, the breakdowns are similar across racial groups—roughly 96%–97% of domestic students are state residents, while about 86%–87% of foreign students are state residents. One notable exception is foreign White students, who exhibit a slightly higher proportion as state residents at 93%.

[5] Roughly 43% of students graduate with a STEM major. At the average introductory math class size of 217 students, this yields about 93 eventual STEM graduates. Our estimates indicate 10 additional foreign students (a 1 standard deviation increase) displaces 6.7 of domestic students from graduating in STEM. Since roughly 50% of foreign students complete STEM majors, five of those 10 will

To identify our effects, we leverage idiosyncratic variation in the foreign student share within introductory math courses taught by the same instructor over time. This is a similar approach, albeit stricter, to other studies using variation in peer composition within school-grade pairs (e.g., Hoxby 2000; Carrell and Hoekstra 2010; Bifulco, Fletcher, and Ross 2011; Carrell, Hoekstra, and Kuka 2018; Anelli and Peri 2019). Our identification leverages variation in exposure to foreign classmates while holding fixed all other classroom factors, such as the instructor, course material, and other peer characteristics. To achieve this, we control for course-by-professor fixed effects and course-by-term effects in our primary specifications. With this specification, the bulk of our identifying variation is from across cohorts, rather than an instructor teaching multiple sections of the same course in a term. In order to account for potentially endogenous curriculum revisions, changes in course demand, and other course-specific trends, we also account for concomitant contextual effects in the classroom by including controls for peer ability, race, and gender composition. Our preferred specification further saturates the model with controls for class size and individual-level background characteristics.

Our setting and granular data help us overcome various methodological challenges when estimating peer spillovers in the classroom. Foreign citizenship has the benefit of being a characteristic that cannot be altered by one's classmates, allowing us to identify peer effects without bias due to reflection. Focusing on students during their first college term helps reduce the scope for selection bias, as new students have less information about the registration process, instructors, and/or their classmates. Highly detailed registration actions of each student allow us to measure the class foreign share prior to the first day of instruction, to limit endogenous sorting after students observe their classmates.

We further provide formal tests that demonstrate our within-course-professor variation is truly idiosyncratic. Balancing tests rule out selection of both domestic and foreign students on an array of observable background characteristics, including race, gender, and ability measures. We also show that the residual variation in the share of foreign peers after partialing out course-by-professor and course-by-term fixed effects is distributed as a randomly generated normal distribution and is uncorrelated with a large array of class characteristics, such as class schedule, average student ability, and the concentration of nationalities among the foreign students. Our results are robust to controlling for foreign student exposure in other courses, accounting for time of day and potential endogenous foreign student information networks. As introductory math classes have high enrollment caps that never bind in our setting, our estimates are not attributable to

graduate in STEM. On net, there is a loss of 1.7 STEM majors (i.e., $6.7 - 5 = 1.7$), which represents about 1.8% of the 93 STEM graduates from the average class.

mechanical crowd-out, whereby the entry of foreign students prevents domestic students from registering for the class.

Why do foreign classmates encourage domestic students to pursue non-STEM majors? We probe several candidate explanations: (1) lower introductory math grades due to direct competition, (2) fewer positive spillovers from communication, (3) lower individual ranking in STEM, and (4) discriminatory preferences. While the empirical context does not allow us to identify any particular channel with precision, we provide suggestive evidence about which potential channels are plausibly relevant and deserve future research.

First, while we do not find any overall effect of foreign peers on the grade earned in the introductory math class, heterogeneous analysis shows a direct negative effect on performance of White male domestic students that is consistent with their higher propensity to choose non-STEM majors as a response to a higher share of foreign peers in the class. This suggests that direct competition in introductory math classes may lead to lower grades for White males, thereby displacing them from STEM majors.

Second, displacement from STEM appears concentrated in classes where foreign peers have particularly low English proficiency. Studies have shown foreign college students to have weaker English proficiency and engage less in communicative activities during class (e.g., Horwitz, Horwitz, and Cope 1986; Erisman and Looney 2007; Rodriguez and Cruz 2009; Stebleton, Huesman, and Kuzhabekova 2010; Stebleton 2011; Yamamoto and Li 2012). Social interactions and effective communication, such as asking clarifying questions, have been linked to success in schooling and labor market outcomes (Borjas 2000; Carrell and Hoekstra 2010; Deming 2017; Carrell, Hoekstra, and Kuka 2018). In a less communicative classroom environment, there are fewer positive externalities from social interactions, and instructors may alter the pace or style of instruction to accommodate nonnative speakers. While we are not able to measure the actual level of interaction within the classrooms, we find this to be a likely mechanism and hope future research will explore more in this direction.

Third, class ranking is shown in the literature to impact students' performance and choices (Elsner and Isphording 2017; Murphy and Weinhardt 2020). In our context, peers can alter the relative ranking/comparative advantage of individuals within a class or labor market. If this constitutes an updated local signal of ability, individuals might respond by specializing in different human capital and labor market choices (Peri and Sparber 2009, 2011; Cicala, Fryer, and Spenkuch 2018). Our analysis shows that domestic students in classes with a higher share of foreign peers indeed rank systematically lower in terms of STEM comparative advantage within the class, even after controlling for their true university-wide comparative advantage in STEM. This phenomenon is driven by the fact that foreign students have on average a much stronger STEM comparative advantage.

Despite the effect on within-class rank, our analysis does not find differential impacts of foreign peers between domestic students sustaining a larger or smaller fall in STEM ability ranking in the introductory math class.

Finally, displacement from STEM may be a result of simple distaste for taking classes alongside foreign students. While we cannot directly test for distaste, we do not find any systematic relationship between the initial foreign share in one's introductory math class and their exposure to foreign classmates in future courses and terms.

Our work contributes to three distinct lines of inquiry. First, our analysis speaks to the impacts of immigration on education within host countries. This study is the first to link exposure to foreign classmates in college classrooms to eventual completion of particular fields of study. Existing studies of foreign peer impacts have focused on primary and secondary education, often in settings outside the United States.[6] Those focusing on higher education have generally examined extensive margin outcomes, and we complement new efforts toward elucidating intensive margin educational outcomes (e.g., Betts and Fairlie 2003; Cascio and Lewis 2012; Orrenius and Zavodny 2015; Chevalier, Isphording, and Lisauskaite 2020).[7] Our inquiry is similar in spirit to Borjas and Doran (2012), who find that the inflow of Soviet mathematicians after the collapse of the Soviet Union had detrimental impacts on the careers of American math professors, reducing their publication rates and displacing them to lower-ranked universities or out of academia altogether. We demonstrate that domestic individuals may experience less detrimental impacts from foreign peers when exposure occurs earlier in the life cycle, where changes in field of study are less costly.

Second, we highlight the importance of peers on human capital investment decisions. Recent work has brought new attention to the importance of major choice, showing that the return to high-paying majors rivals the high school–college wage gap (Altonji, Blom, and Meghir 2012), exceeds the return to attending selective institutions (Arcidiacono, Aucejo, and Hotz 2016; Kirkeboen, Leuven, and Mogstad 2016), and has been widening over time (Altonji, Kahn, and Speer 2014). This paper highlights that peer composition can have a large effect on investments in particular fields of study.

Finally, our analysis of labor market outcomes demonstrates how early shocks in education can persist well into the labor market and carry implications for how immigration of young students may affect the aggregate

[6] For example, Gould, Lavy, and Paserman (2009), Diette and Oyelere (2012), Brunello and Rocco (2013), Geay, McNally, and Telhaj (2013), Ohinata and Van Ours (2013), Diette and Oyelere (2014), Ballatore, Fort, and Ichino (2018), Conger (2015), Ohinata and Van Ours (2016), Figlio and Özek (2019), and Frattini and Meschi (2019).

[7] Papers on US higher education have focused on international students and enrollment or graduation (Betts 1998; Hoxby 1998; Borjas 2004; Jackson 2015; Hunt 2017; Machin and Murphy 2017; Shih 2017).

supply of STEM skills. A rough back-of-the-envelope calculation indicates that the total number of STEM graduates may fall slightly, as increases in foreign students only partially offset the decreases in domestic STEM graduates. Applying our estimate to the average class size indicates that 10 additional foreign students would reduce the number of domestic STEM graduates by 6.7. Of those 10 foreign students, about five will go on to complete STEM degrees. As such, the total supply of STEM graduates shrinks by about two, representing roughly 2% of the total number of STEM graduates expected from the average class. We note, however, that a smaller STEM supply may not be detrimental to innovation. Hunt and Gauthier-Loiselle (2010) show that foreign STEM workers patent at almost double the rate of native workers. Kerr and Lincoln (2010) show that skilled immigrants increase innovation within firms without crowding out, and possibly even crowding in, innovation from natives. Hence, it is not entirely clear that the slight reduction in total STEM graduates would necessitate less innovation in the long run. Furthermore, as the skilled immigrant population in the United States expands there may be important long-run effects on the STEM supply if the children of skilled immigrants become increasingly important in our colleges and universities and in the STEM workforce.

The implications of our findings for broader policies surrounding foreign enrollment will vary depending on context. Our focus on introductory math courses has broad scope, as the subject matter and general way of teaching calculus-based courses are fairly similar across higher education institutions. However, US higher education institutions are quite diverse on a wide array of attributes, which need to be considered when assessing the impact of foreign students. The cost of switching majors, course enrollment caps, or the relative skill sets of foreign and domestic students are a few such attributes.

We proceed by describing the institutional setting and our data in section II. Section III details our empirical framework, clarifies our identifying variation, and demonstrates it is consistent with truly random variation in foreign class shares. Section IV discusses how we overcome the challenges of causal identification in our setting and provides various tests for selection on observables. Results and robustness checks are presented in section V. Section VI describes and tests various mechanisms underlying our main findings. Section VII concludes.

II. Data

This paper uses administrative data from a selective US public university that follows a trimester system, with three terms per academic year. The university consistently ranks in the top 50 public universities in *U.S. News and World Report* rankings. Our data contain students' academic records for each term from academic years 2000/01 to 2011/12. Records contain the class registration activity of students, which we use to reconstruct the rosters of each class. For each class we observe the course title, instructor, and term offered. Available student background measures include SAT scores, high school grade point average (GPA), race, gender, US citizenship status, and nationality. Student-level outcomes include date of graduation, major at graduation, declared major (term by term), cumulative GPA, and grades in each course.

Enrollment at our institution is quite large, with undergraduate students comprising roughly 80% of the total student body. The student body is highly diversified, with current enrollment figures around 28% Asian, 25% White, 22% Hispanic, and 15% international. Nearly 60% of students receive financial support. The institution is regarded as highly selective, with average SAT scores of incoming students above the national average.

The university provides a wide number of fields of study. Students can earn bachelor's degrees in more than 100 different majors, with STEM fields (e.g., biology, chemistry, and mechanical engineering) comprising half of the top 20 most popular majors.[8] Students may enter undeclared but are required to formally declare a major before completing two full-time years of course work. Switching majors requires obtaining approval from an advisor in the major they wish to leave and from an advisor in the major they wish to join. Approximately 50%–60% of students graduate within 4 years, and 80%–85% graduate within in 6 years.

Generally, students register for courses in the prior term. First-term freshmen register for classes before they actually begin college. The university offers in-person onboarding prior to the start of the first semester, where students can meet with academic counselors and advisors to help them schedule their first semester. For nonfreshmen, registration occurs over the course of a few days, and registration time slots are randomly assigned within level (i.e., sophomores, juniors, seniors, etc.), with more senior levels receiving earlier registration priority.

Our focus is on introductory math classes, which never exhibit a binding cap. Introductory classes are large and occur in lecture halls. Instead of splitting each class into several discussion sections for extra tutoring, the math department centralizes tutoring for all introductory courses. Hence, there are no discussion sections. Instead, the department offers a tutoring office that is open during the day for all students to seek assistance.

In what follows, we provide more detail about the institution we study, specify the introductory math courses we focus on, and then describe the students and outcomes in our sample.

[8] For the full list of majors classified as STEM, see table A1 (tables A1–A3 are available online).

A. Introductory Math Courses

We focus on domestic students taking introductory, calculus-based math courses during their first term of university attendance.[9] This choice is motivated by the fact that these courses have long been viewed as gateways to STEM degrees (Steen 1988) and that all STEM fields require early and satisfactory completion of an introductory math course to progress in the major. Indeed, these introductory math courses are by far the most frequently enrolled among all STEM introductory courses in the university under analysis. Approximately 70% of all students in our data take an introductory math course at some point during their undergraduate studies, with more than 40% of domestic students enrolling during their first term.[10] Within US higher education, introductory math courses generally cover uniform subject material—calculus—thereby limiting the scope for potential issues arising from differences in subject matter breadth and depth while also enhancing the external validity of our findings. These courses have very high enrollment caps (999 students) that never bind in our institutional setting—enrollment never exceeds 40% of the cap. This implies that students cannot be mechanically crowded out of classes because of high demand.

Table 1 lists the introductory math courses in our primary sample. For each course we also provide the total number of domestic first-term freshmen, the total number of domestic students, the total number of foreign students, the average percent foreign across classes, the average class size, and the total number of classes. We consider a course to be introductory if first-term freshmen can enroll, if it satisfies the university-level quantitative course general education requirement, and if it is a prerequisite for at least one STEM major. Introductory math classes mainly cover calculus topics and have an average class size of 217 students. While we include high-achieving students who take more advanced courses (e.g., Calculus III) in their first term, the basic Calculus I course comprises the majority of the domestic first-term freshmen and a large number of classes in our data. While our primary analysis leverages variation in all of these courses, we also show our results are unchanged when using only Calculus I. First-term domestic students make up 65% of domestic students and 54% (16,828 of a total of 31,032 students) of total enrollment, indicating that these are in fact introductory-level courses.

[9] These students enroll in these courses before showing up on campus. Their enrollment decision is therefore hardly influenced by environmental factors and is shown to be exogenous to the class share of foreign peers, as we show in sec. III.

[10] For reference, the second most frequently enrolled STEM introductory courses are those of the chemistry department, which have an overall enrollment that is only two-fifth of that for introductory math courses, followed by computer science introductory courses, which have an enrollment equivalent to only one-twelfth of that for introductory math courses.

Table 1
List of Math Courses

	Domestic First-Term Freshmen	Total Domestic Students	Total Foreign Students	Average Percent Foreign	Average Class Size	Total Classes
Precalculus	1,838	2,307	246	9.5	289	15
				(2.7)	(96)	
Calculus I	7,031	8,851	1,046	10.3	246	52
				(2.9)	(84)	
Calculus I (Advanced)	4,965	5,377	990	15.4	207	35
				(3.7)	(55)	
Calculus II	392	2,379	300	10.0	198	18
				(3.7)	(61)	
Calculus II (Advanced)	922	1,553	351	17.5	151	14
				(4.2)	(33)	
Calculus III	54	1,376	190	10.6	210	11
				(3.6)	(64)	
Calculus III (Advanced)	299	1,516	316	15.2	155	15
				(4.3)	(42)	
Calculus IV (Advanced)	40	1,016	199	13.8	142	12
				(5.7)	(46)	
Total/average	16,828	25,701	3,810	12.3	217	179
				(4.4)	(79)	

NOTE.—This table displays the list of introductory mathematics courses offered by the university under analysis. Advanced courses cover similar material to nonadvanced ones, but with greater depth. The sample includes 16,828 freshmen domestic students enrolling in introductory math courses in their first term of college attendance. Standard deviations are presented in parentheses where applicable.

B. Foreign Class Share

We measure exposure to foreign students at the class level, and individuals are identified as foreign if they are not US citizens. The class is a natural unit where interactions might occur as students attend lectures together and are evaluated jointly by the professor using the same exams and assignments.[11] Moreover, for most of these courses there is no separate discussion section to which students are assigned, as the math department instead offers a centralized tutoring office. We measure exposure to all foreign students in one's introductory math class by calculating the share of one's classmates who are foreign. To reduce endogenous selection, we leverage detailed registration records to measure the foreign class share on the day prior to the first day of instruction. As such, our foreign share is measured

[11] In rare instances when a single professor teaches more than one class of a course in a term, the classes are treated as distinct. In the data, this occurs only six times out of 179 different course-professor offerings.

before students are physically present to observe their classmates, meet the professor, or examine the syllabus.

Table 1 shows the average class foreign share is 12.3% and is slightly lower/higher in more basic/advanced courses. Figure 1 shows the overall variation in the foreign share across introductory math classes in our sample. While typically ranging between 8% and 15%, some classes have less than 5%, and a few have greater than 20%. To abstract from the many potential differences across courses (e.g., course rigor and material, student ability, and preparedness) and across instructors (e.g., instructor pedagogy), we choose to exploit variation in foreign shares within courses taught by the same professor over time. We clarify this variation further in section III and discuss the necessary identifying assumptions of this approach in section IV.

C. Analytical Sample Descriptive Statistics

Our resulting analytical sample comprises domestic first-term students enrolled in an introductory math class. We note that the sample contains only enrollment in fall terms since the first term for freshmen is always the fall term. Although our data continues through 2012, we restrict the sample to 2006 and prior so that we can observe 6-year graduation outcomes for all students. This yields a sample of 16,828 domestic first-term freshmen enrolled in introductory math classes between the fall of 2000 and the fall of 2006.

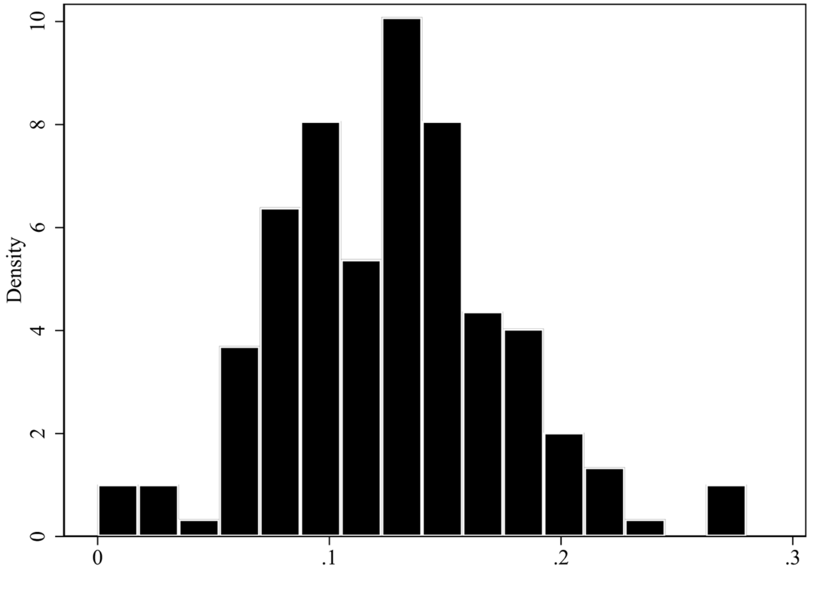

FIG. 1.—Variation in foreign share in introductory math courses. This figure displays a histogram of the foreign share across introductory math classes in our sample. Introductory math classes are defined by unique course, professor, and term combinations.

Table 2
Background Summary Statistics

	All Students		Introductory Math Sample	
	Domestic (1)	Foreign (2)	Domestic First-Term Freshmen (3)	Foreign Classmates (4)
Female	.56	.53	.50	.48
	(.50)	(.50)	(.50)	(.50)
White	.47	.16	.41	.12
	(.48)	(.33)	(.48)	(.30)
Asian	.37	.71	.48	.77
	(.46)	(.43)	(.49)	(.40)
Minority	.15	.13	.10	.11
	(.35)	(.32)	(.29)	(.30)
Black	.03	.02	.02	.02
	(.17)	(.13)	(.13)	(.13)
Latino	.12	.11	.08	.09
	(.31)	(.29)	(.27)	(.28)
High school GPA	3.70	3.70	3.76	3.72
	(.30)	(.26)	(.33)	(.30)
SAT math	599.45	599.62	629.36	617.90
	(74.99)	(76.40)	(71.91)	(87.14)
SAT verbal	562.90	510.62	573.84	491.14
	(79.63)	(90.42)	(84.49)	(104.15)
SAT	1,160.18	1,105.63	1,200.35	1,099.65
	(136.34)	(138.31)	(135.62)	(162.88)
Composite admission score	7,394.68	7,429.27	7,510.24	7,390.66
	(758.58)	(715.93)	(831.34)	(911.75)
Observations	45,293	7,165	16,828	3,810

NOTE.—Shown are means for enrolled students from the fall of 2000 to the fall of 2006. Standard deviations are in parentheses. Column 3 refers to our analysis sample of 16,828 first-term domestic freshmen. Composite admission score is calculated by the admissions office using a weighted sum of various background ability and traits, which includes some measures available in our data as well as other ability measures that are not available.

Table 2 provides various summary statistics of students in the university we study. Columns 1 and 2 refer to all domestic and foreign students enrolled during the period under analysis (2000–2006). Column 3 describes our primary analysis sample of domestic first-term freshmen in introductory math courses. Column 4 displays statistics for foreign students in introductory math courses. While 56% of domestic students are female, only half of first-term domestic freshmen who enroll in introductory math courses are female. Asians, who account for only 37% of all domestic students overall, are overrepresented in introductory math courses, comprising nearly half of all of the first-term freshmen enrolled in introductory math courses. A similar pattern is observed for foreign students. Nearly 80% of all foreign students are Asian.[12]

[12] International students (those on a temporary student visa) account for 11% of our foreign peer population. Their small sample size limits our ability to statistically distinguish effects of this group from those of foreign students.

Foreign students do not appear to be substantially different in terms of ability in the general student population. One exception is that foreign students exhibit substantially lower SAT verbal scores, reflecting their lower English ability. This difference in English ability is magnified when comparing domestic first-term freshmen and their foreign classmates in introductory math classes—SAT verbal scores of foreign classmates are almost a full standard deviation below those of domestic students. Although differences in SAT verbal are the most salient, domestic freshmen outperform their foreign classmates in introductory math courses on all measures of background ability.

Table 3 summarizes outcome measures for our sample of students. We focus on major at graduation, as it is a definitive measure of skill acquisition. Students are classified into one of three broad groups—STEM degree, social science degree, or arts and humanities degree—on the basis of their major at graduation (further details are provided in table A1). We measure graduation within 6 years, and those who do not complete a degree within 6 years are referred to as "dropouts"; however, a small number may actually take 7 years or more to graduate.[13]

Panel A provides a summary of academic outcomes. Approximately 82% of entering domestic freshmen graduate within 6 years, whereas 18% drop out or take more than 6 years. While domestic students graduate with an average GPA of 3.05, their foreign classmates in introductory math courses perform slightly lower. Students who graduate take slightly more than 16 terms, or 5.33 years (three terms per year) to complete their degree. Nearly half of all students attending introductory math courses earn a degree in a STEM field, with social science comprising less than a third. Only around 8% of students earn degrees in arts and humanities.

Panel B focuses on students' labor market outcomes, which come from two additional sources. These data allow us to explore whether there are persistent effects from peers beyond graduation. First is a measure of expected earnings from the Hamilton Project (Hershbein and Kearney 2014), estimated using ACS data.[14] Every student in our data is assigned an earnings level based on the country average for his or her major for 1, 6, 15, and 30 years after graduation. These earnings are not student specific (e.g., all economics majors are assigned the same value) and thus represent a generic estimate of student expected labor market success after college

[13] For our early cohorts (2000, 2001, 2002), for which we can observe graduation outcomes for at least 11 years, we find that among students not graduating within 6 years, fewer than 6% go on to graduate within 11 years.

[14] Hershbein and Kearney (2014) use earnings data from the US Census Bureau's ACS between 2009 (the first wave for which college major was asked) and 2012. Earnings are defined as the sum of wages, salaries, and self-employment business income and refer to the year prior to survey.

Table 3
Outcome Summary Statistics for Introductory Math Sample

	Domestic First-Term Freshmen (1)	Foreign Classmates (2)
A. Academic outcomes:		
Graduate	.82	.78
	(.38)	(.42)
Drop out	.18	.22
	(.38)	(.42)
Time to degree (terms)	16.41	16.37
	(2.48)	(3.10)
Graduation GPA	3.05	2.96
	(.44)	(.45)
Graduate STEM	.48	.44
	(.50)	(.50)
Graduate social science	.27	.27
	(.44)	(.44)
Graduate arts and humanities	.08	.06
	(.26)	(.24)
B. Labor market outcomes:		
Expected earnings at graduation	23,231	23,768
	(13,793)	(15,462)
Expected earnings 6 years after graduation	38,552	38,765
	(20,617)	(22,968)
Expected earnings 15 years after graduation	49,729	50,154
	(26,642)	(29,832)
Expected earnings 30 years after graduation	52,760	52,905
	(30,907)	(34,071)
Occupation-based personal income	63,081	62,695
	(21,990)	(21,672)
Occupation-based family income	140,766	145,298
	(89,897)	(98,488)
Fraction with occupation linked	.74	.66
	(.44)	(.47)
Fraction with STEM occupation	.44	.51
	(.50)	(.50)
Observations	16,828	3,810

NOTE.—This table reports summary statistics for various outcome measures. Column 1 refers to our analysis sample of 16,828 domestic first-term freshmen. Column 2 refers to the foreign classmates of domestic freshmen enrolling in introductory math courses in their first term of college attendance. All earnings figures are reported in thousands. Expected earnings refers to the expected earnings based on a student's major according to data from the Hamilton Project. Occupation-based measures come from observation-specific occupational matching described in sec. C of the appendix.

conditional on their major of graduation.[15] Descriptive statics in table 3 show that domestic freshmen attending introductory math courses have expected earnings along their career similar to those of their foreign classmates. This

[15] Expected earnings and earnings profiles calculated by Hershbein and Kearney (2014) rely on the ACS cross section of individuals from many cohorts only partially overlapping with the cohorts in our analytical sample. Using these values as outcomes

suggests that on average the domestic students in our analytical sample choose majors that deliver similar earning levels in expectations.

Our second measure is a student-specific STEM occupation indicator. In conjunction with university administrators, we systematically gathered data on individual student job descriptions via publicly available information on the internet and linked it to their student records. We match occupational information for 74% of students in our analytical sample. Occupational descriptions are then matched to Standard Occupational Classification (SOC) codes using an algorithm based on the O'NET dictionary of occupation titles. We index each occupation as STEM or non-STEM using a classification provided by the Bureau of Labor Statistics.[16] Based on the matching, we estimate that 44% of domestic freshmen are working in STEM fields, while 51% of foreign students are. Based on each individual SOC code we link occupational-based expected earnings, calculated using ACS data as the average earnings of all college graduates born in the same cohorts as our students working in that occupation. Estimated earnings are very similar across the two groups.

These two measures have distinct advantages and shortcomings. Both major and occupation outcomes reflect the interaction of student choices and various constraints (e.g., major grade requirements, occupation labor demand). Notably, the occupation outcome occurs later in the life cycle. The measure of major-specific expected earnings has the advantage of not being subject to bias arising from inaccuracy in measuring students major at graduation. A disadvantage is that expected earnings measures are not student specific. The occupation indicator measure does capture individual-level outcomes; however, it is subject to potential inaccuracies due to the imperfections in matching. Hence, the occupation-specific expected earnings measure suffers from both inaccuracy and the loss of individual-level earnings information. Nonetheless, the fact that we estimate similar effects when using these two distinct measures of earnings helps to increase the reliability of our findings.

for our cohorts thus implies assuming a certain degree of persistence in the returns to college major across cohorts. Moreover, average earnings by college major from the Hamilton Project are representative of the entire US population of college graduates. Relying on them for our sample requires assuming that labor market outcomes for graduates from the university under analysis do not deviate substantially from those of the average US graduate. Given the characteristics of this university, this assumption is fairly reasonable.

[16] See https://www.bls.gov/soc/Attachment_C_STEM.pdf. In particular, we define STEM occupations as those in categories 1 (life and physical science, engineering, mathematics, and information technology) and 4 (health). The full matching process is described in detail in sec. C of the appendix (available online).

III. Empirical Methodology

We aim to identify the causal impact of foreign classmates on completing a STEM degree and working in a STEM occupation. Our empirical design is motivated by the ideal experiment, in which identical sets of students would experience random variation in foreign peers while everything else about the class—such as the professor, course material, other peer traits, and class size—would remain the same. Lacking such a natural experiment, we leverage idiosyncratic variation in foreign class shares within courses taught by the same professor over time.[17]

We estimate the impact of exposure to foreign students using a linear probability model:[18]

$$Y_{icpt} = \alpha + \beta \frac{F_{cpt}}{N_{cpt} - 1} + \sigma_{cp} + \sigma_{ct} + \gamma \bar{X}_{cpt} + \delta X_i + \varepsilon_{icpt}, \quad (1)$$

where Y_{icpt} represents an outcome for student i who attended an introductory math class, identified by course c, professor p, and term t. Exposure to foreign students is measured as the share of individual i's classmates who are foreign, $F_{cpt}/(N_{cpt} - 1)$, where F and N represent the number of foreign students and the total number of students registered in the class on the day prior to the first day of instruction, respectively. We standardize the foreign share in our sample so that our primary coefficient of interest, β, can be interpreted as the impact of a 1 standard deviation increase in foreign share on outcome Y.

To leverage variation within course-professor, we control for course-by-professor fixed effects (σ_{cp}), which account for fixed differences—such as teaching style, course difficulty, or workload—that might give rise to endogenous student selection across course-professor pairs. We also account for course-by-term indicators to absorb confounding time-varying course-level factors, such as curriculum revisions or growing student demand for particular courses.

We control for other class characteristics ($\bar{X}_{cpt}$) to account for common classroom shocks. Class-level controls include peer ability measures—average peer SAT math, SAT verbal, and high school GPA—and average peer race and gender composition. Results are robust to controlling for class

[17] Many papers have utilized cross-cohort within-class variation to estimate educational peer effects (Hoxby 2000; Hanushek et al. 2003; Vigdor and Nechyba 2006; Carrell and Hoekstra 2010; Bifulco, Fletcher, and Ross 2011; Anelli and Peri 2019). By included instructor-specific fixed effects rather than just course-specific ones, we are reducing potential endogenous sorting or student choices that may relate to heterogeneous teaching methods or instructor turnover.

[18] Results from logit and probit estimation (available on request) yield average marginal effects that are similar in size. However, studies (e.g., Greene 2004) have cautioned against using logit or probit estimation with fixed effects, as it can generate biased and inconsistent results.

size, as prior studies have found important interactions between foreign student inflows and class size (Ballatore, Fort, and Ichino 2018). We also add individual-level controls: race, gender, SAT verbal and SAT math scores, and high school GPA. Finally, ε_{icpt} is a mean-zero error term. We cluster standard errors at the professor level.

Before discussing the identification challenges of our empirical strategy, we provide a visual representation of the nature and magnitude of our variation. Figure 2 displays the class foreign share over time for 10 randomly sampled course-professor pairs. Connected points facilitate visual tracking of the foreign class share, within the same course-professor pair, over time. For example, points A, B, C, and D refer to distinct classes of the same course (e.g., Calculus I) taught by the same professor (e.g., Jane Doe) over different terms. The Calculus I class taught by Jane Doe in the fall of 2000 (point A) has nearly double the foreign share than the one taught by Jane Doe in the fall of 2001 (point B). Our empirical design draws comparisons in the outcomes of domestic first-time freshmen students enrolled in class A against those in class B. Students across these two classes took the same course (Calculus I) with the same professor (Jane Doe) but were exposed

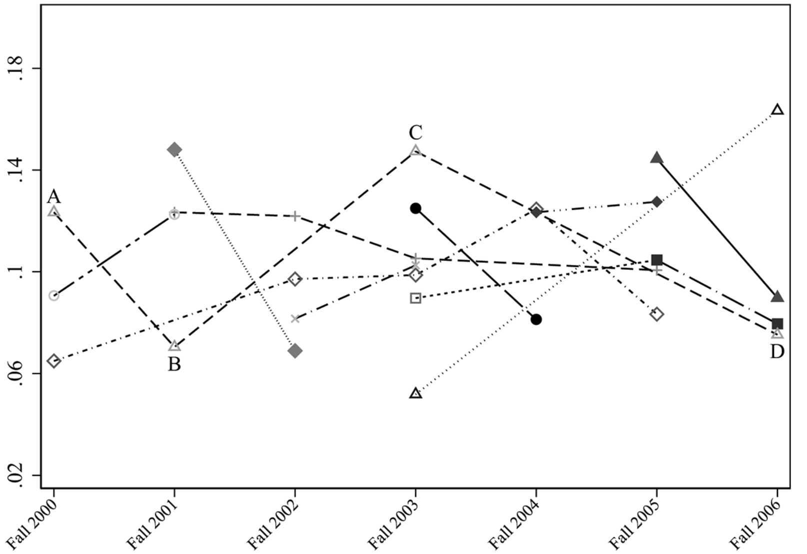

FIG. 2.—Foreign share variation within course-professor over time. This figure provides a visual illustration of our within-course professor variation for 10 randomly sampled course-professor pairs. Each point represents the foreign class share for a given introductory math class. Classes of the same course, taught by the same professor, are connected with lines. Terms are displayed on the horizontal axis, and share of foreign students in the class is displayed on the vertical axis.

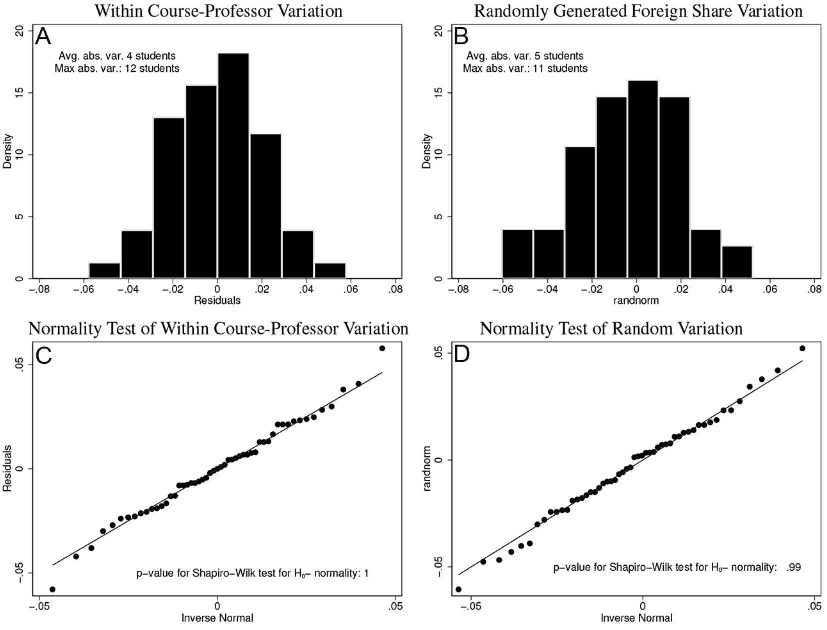

FIG. 3.—Within-course-professor variation versus random variation. These graphs compare our within-course-professor variation in foreign shares to randomly generated foreign shares. *A* plots a histogram of our within-course variation in foreign class shares after partialing out course-by-professor and course-by-term fixed effects. *B* plots a histogram of foreign class share variation after randomly drawing foreign shares from a normal distribution, using the mean and standard deviation of our observed within-course-professor residuals. Intuitively, the randomly drawn foreign shares should be normally distributed. If our within-course-professor variation is compatible with random variation, it should also be normally distributed. *C* formally tests whether our within-course-professor variation is normally distributed using the Shapiro-Wilk test for normality. *D* provides the same test for the randomly drawn residuals.

to very different levels of foreign classmates by virtue of entering the university and enrolling in introductory math in different terms. We argue that the difference in the foreign class share in A and B is driven by idiosyncratic fluctuations and that students in the two classes are comparable.

In figure 3, we provide visual evidence about the magnitude of our identifying variation. We first plot our within-course variation in figure 3*A*, which displays a histogram of the foreign class share after partialing out course-by-professor and course-by-term fixed effects. The residual variation in foreign share is still substantial and ranges between −0.6 percentage points and +0.6 percentage points relative to the within-course-professor mean. In an average-sized class this is equivalent to ±4 students on average and a maximum of ±12 students.

We then visually compare our within-course-professor variation against random variation. For each class in our sample we randomly draw its foreign share from a normal distribution, using the mean and standard deviation of our observed within-course-professor residuals. The histogram of randomly drawn foreign shares is displayed in figure 3*B*.

Intuitively, the randomly drawn foreign shares should be normally distributed. If our within-course-professor variation is compatible with random variation, it should also be normally distributed. Figure 3*C* formally tests whether our within-course-professor variation is consistent with a normal distribution. The Shapiro-Wilk test for normality fails to reject the null hypothesis that the variation is normally distributed (*p*-value of 1). For consistency, figure 3*D* provides the same test of normality for the randomly drawn residuals.[19] These tests show that our within-course-professor variation is consistent with the magnitude we would expect from random variation. In figure 3*A* and 3*B* we also report the average and maximum variance in foreign students in an average-sized class. The magnitude of the within-course-professor variation is nearly identical to that of random variation. Hence, this check helps assure that our variation is idiosyncratic in nature and comparable in magnitude with a random normal.

IV. Identification Challenges

To establish a causal relationship between foreign classmates and the outcomes of domestic first-term freshmen, we first demonstrate that our within-course-professor variation is robust to common challenges in estimating peer effects: reflection, selection, and common shocks (Manski 1993; Moffitt 2000; Sacerdote 2011). We discuss in greater detail how our institutional setting, data, and identification strategy provide unique advantages to overcome each of these issues. We also perform tests for selection on observables and class-level common shocks to assess the scope for bias in estimation.

A. Reflection

Our approach addresses issues of reflection that occur when explanatory peer measures can potentially be influenced by individuals. This is usually problematic when the peer measures is the average outcome of one's peers. However, we examine a peer background trait—citizenship—that is measured before students meet their classmates. Thus, it is highly unlikely that

[19] In fig. A1 (figs. A1, B1 are available online) we also perform this test using less demanding fixed effects. Specifically, when we use course, professor, and term fixed effects, the same test rejects that this level of variation is normally distributed (*p*-value of .06). When forcing variation to come from within course-professor by including course-by-professor fixed effects (and also term fixed effects), the variation begins to resemble a normal distribution.

domestic students could reasonably affect the citizenship status of their foreign classmates before they even physically enter the classroom.[20]

Because we do not include peer outcomes, $\bar{Y}_{-icpt}$, in our specification, this also means that our model estimates a combination of the endogenous and exogenous peer effects (Manski 1993; Carrell, Sacerdote, and West 2013). While this is a limitation common to most peer effect studies due to the challenge of finding a credible source of identification to disentangle the two, mechanisms driving peer effects are often blends of these two channels anyway, so we do not feel that estimating a combination of the two channels detracts from the model.

B. Selection

Selection of students into classes that is related to the foreign class composition would bias our estimates. We take several precautions to help limit selection in our identification. First, we focus on first-term freshmen, who have little prior experience or knowledge about professor reputation, course detail, and class composition at the time of registration.[21] To reinforce this, we leverage detailed registration records to reconstruct the roster of each class one day prior to the first day of instruction. The foreign class share and all other class-level variables are therefore measured before students ever physically attend class to observe their classmates, meet the professor, and receive an introduction to the course.

Second, while students undoubtedly sort across courses and/or professors, our identifying variation renders endogenous selection within course-professor quite challenging for first-term freshmen. Recall that our design compares the foreign share of a class offered in a fall term to the same class (course-professor) offered in future fall terms (e.g., comparing points A, B, C, and D in fig. 2). Endogenous sorting within course-professor for first-term freshmen would arise only by either delaying (e.g., start college next year instead of this year) or accelerating (e.g., start college this year instead of next year) enrollment. This is further complicated by the fact that instructor course assignments are decided during the prior term. Hence, for example, class offerings for the fall of 2002 are decided and published in the spring of 2002. Students deciding whether to enroll in Jane Doe's Calculus I class in the fall of 2001 have little information about whether Jane Doe will teach Calculus I in the fall of 2002 or after—oftentimes the instructors themselves may not know future teaching assignments.

[20] Additionally, because domestic and foreign students are mutually exclusive groups, our analysis does not suffer from more recent concerns of mechanical negative bias (e.g., Guryan, Kroft, and Notowidigdo 2009; Fafchamps and Caeyers 2020).

[21] Enrollment of freshmen for first-term courses is done online even before students are physically present on campus.

While sorting within course-professor is quite difficult for first-term freshmen, it might be more feasible for nonfreshmen students. Selection by nonfreshmen within course-professor has the potential to endogenously alter other peer classroom characteristics. For example, domestic sophomores and juniors with poor math ability might delay enrollment within course-professor if they perceive greater competition from foreign students prior to the first day of instruction. Similar to endogenous information networks in immigrant labor markets (Munshi 2003; Cadena 2013), foreign students could leverage immigrant networks to select classes within course-professor that might provide them with an unobservable advantage over domestic students.

We provide various checks to examine the extent of selection. We formally test for selection on observables using balancing tests. Additionally, in section V.A we also explore the potential role played by immigrant networks by controlling for an Herfindahl index measuring concentration of origin countries among the foreign peers. To test for selection on observables, we examine whether the class foreign share is systematically correlated with observable background characteristics of enrolled students. Importantly, we test for selection not only among first-term freshmen but also among other domestic and foreign nonfreshmen in the class, as endogenous selection by any group could change the classroom composition. Finding little evidence of selection on observables helps increase confidence regarding selection on unobservables (Oster 2019).

Specifically, we estimate the following regression model:

$$X_i = \alpha + \delta \frac{F_{cpt}}{N_{cpt} - 1} + \sigma_{cp} + \sigma_{ct} + \epsilon_{icpt}. \tag{2}$$

The dependent variable in equation (2) represents measures of individual background characteristics of student i (X_i). Including course-by-professor and course-by-term fixed effects allows us to examine whether selection occurs within course-professor pairs. Since foreign student information networks might operate differently from domestic students, we separately examine each group.

The results of these tests are displayed in table 4. Each column corresponds to a different individual background characteristic (X_i).[22] Panel A performs these exogeneity tests for all domestic students, while panel B performs the tests for all foreign students. None of the estimates in panel A and only one estimate in panel B are statistically distinguishable from zero at any meaningful level of confidence—consistent with what would be expected under multiple hypothesis testing. The estimate in column 8 of panel B indicates that a 1 standard deviation increase in foreign classmates is associated

[22] The sample of 25,701 include both the 16,828 domestic first-term freshmen and other domestic students (i.e., non-first-term freshmen, sophomores, juniors, and seniors) enrolled in the introductory math courses.

Table 4
Exogeneity Checks: Selection on Observables

	Female (1)	White (2)	Asian (3)	Latino (4)	Black (5)	Minority (6)	SAT Math (7)	SAT Verbal (8)	High School GPA (9)	Composite Admission Score (10)
A. Domestic students:										
Foreign share	−.01	−.01	.02	−.00	−.00	−.01	1.95	−1.20	.01	22.15
	(.01)	(.01)	(.01)	(.01)	(.00)	(.01)	(1.78)	(2.10)	(.01)	(15.96)
Mean(Y)	.51	.42	.46	.10	.02	.12	618.93	568.08	3.74	7,443.55
Observations	25,701	25,701	25,701	25,701	25,701	25,701	25,701	25,701	25,701	25,701
R^2	.11	.02	.02	.01	.01	.02	.15	.03	.03	.29
B. Foreign students:										
Foreign share	−.00	−.01	.01	.01	−.01	.00	2.98	−13.45***	−.02	−46.58
	(.04)	(.01)	(.02)	(.01)	(.01)	(.01)	(4.64)	(4.09)	(.02)	(30.78)
Mean(Y)	.51	.12	.78	.09	.02	.10	619.00	490.02	3.72	7,439.49
Observations	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810	3,810
R^2	.12	.05	.06	.08	.04	.07	.19	.05	.05	.40

Note.—This table displays estimates from eq. (2). Regressions include controls for course-by-term and course-by-professor fixed effects. Outcome variables across the columns are individual background characteristics. Panel A reports results for all domestic students in introductory math courses. Panel B reports results for all foreign students in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor.

*** Significant at the .01 level.

with a 13.45-point-lower SAT verbal score for foreign students. Despite being statistically significant, the magnitude of this effect is exceedingly small (one-tenth of a standard deviation) and unlikely to make a meaningful difference in the classroom environment. Nonetheless, to limit the scope of potential selection bias, we include these background characteristics as controls when we analyze effects on STEM graduation.

C. Common Shocks

Causal identification in our setting also requires that there are no other unobserved factors that also vary within courses taught by the same professor and are endogenously related to the class foreign share. To assess potential bias from common class-level shocks, we examine whether any of our observable class-level traits are systematically correlated with the class foreign share, within courses taught by the same professor. We collapse our data to the class level and formally test for correlations using the following specification:

$$\bar{X}_{cpt} = \alpha + \psi \frac{F_{cpt}}{N_{cpt}} + \sigma_{cp} + \sigma_{ct} + \epsilon_{cpt}. \quad (3)$$

Equation (3) regresses class characteristic $\bar{X}$ on the class foreign share (F/N). We control for course-by-professor and course-by-term effects so that we focus on variation within course-professor over time. As before, we standardize the foreign share in the sample so that the coefficient can be interpreted as the impact of a 1 standard deviation increase in the class foreign share.

The results of this exercise are displayed in table 5. Different class characteristics are examined across the columns. Columns 1–6 show no systematic correlation between the class foreign share and class gender, race, or ability composition—for brevity we report only the class average composite admission score, which is a weighted combination of SAT math, SAT verbal, and high school GPA.

Columns 7 and 8 further show no significant correlation between class size or the time of day in which the class is taught.[23] We note that all introductory math classes are taught on a Monday–Wednesday–Friday schedule, so there is no variation in day of week. Despite not being statistically significant at conventional levels, we do acknowledge that the magnitude of the coefficient in column 7 is quite large—a 1 standard deviation increase in foreign share is associated with an increase in class size of 41 student, almost 25% of the mean. This is not surprising, however, as introductory math courses are in practice uncapped and foreign students have been

[23] All introductory math classes are 50 minutes long. There are a maximum of 11 possible class times throughout the day, with the earliest beginning at 8 a.m. and the latest at 6 p.m.

Table 5
Exogeneity Checks: Class-Level Correlations

	Female Share (1)	White Share (2)	Asian Share (3)	Latino Share (4)	Black Share (5)	Average Composite Admission Score (6)	Class Size (7)	Time of Day (8)	Nonfreshmen Foreign Share (9)	Nationality Herfindahl Index (10)
Foreign share	−.01	−.03	.03	.00	−.00	17.54	41.45	−.37	.01	−.09
	(.02)	(.02)	(.02)	(.01)	(.00)	(34.45)	(25.90)	(.74)	(.01)	(.11)
Mean(Y)	.47	.38	.49	.10	.02	7,432.52	173.36	5.26	.05	.08
Observations	179	179	179	179	179	179	179	173	179	179
R^2	.99	.94	.96	.88	.90	.99	.94	.94	.99	.77

Note.—This table displays estimates from eq. (3). Regressions include controls for course-by-term and course-by-professor fixed effects. Data are collapsed to the class level, and outcome variables across the columns are class average background characteristics. The foreign share is standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor.

shown to affect class size in other contexts (Ballatore, Fort, and Ichino 2018). Hence, our preferred specification will include class size as a control.

Finally, columns 9 and 10 examine two different measures of the foreign class composition: the foreign nonfreshmen share and a Herfindahl index based on foreign student nationality. Because related work has shown that immigrant information networks can lead to endogenous sorting across labor markets (Cadena 2013), similar information networks might operate among foreign students, particularly among foreign nonfreshmen, who have greater ability to sort within course-professor. As such, systematic sorting of many upper-class foreign students would also materialize in changes in the foreign share. Nonetheless, column 9 shows no systematic correlation between the class foreign share and the class nonfreshmen foreign share. As an alternative check, we calculate a Herfindahl index based on foreign student's reported nationality.[24] Information networks may likely operate more strongly among students from the same nationality. In this case, systematic sorting of foreign students relying on nationality-specific information networks might result in stronger/weaker concentrations of students from the same nationality. The results in column 10, however, show no correlation between the class foreign share and the nationality-based Herfindahl index.

The lack of a systematic correlation between the class foreign share and observable class-level characteristics helps bolster our confidence that remaining unobservable class-level shocks are likely to be pseudorandom in nature. To further assess the potential for common shocks, we demonstrate in section V that our main findings are robust to controlling for these characteristics.

V. Results

We now proceed to our main results on the effect of foreign classmates in introductory math courses in table 6. We first compare our preferred within-course-professor variation (col. 4) to alternative types of variation in columns 1–3. These comparisons help elucidate the trade-off between statistical power and exogeneity and highlight that our preferred identifying variation is demanding in terms of exogeneity while retaining sufficient power in estimation. In columns 1–4 we control for the most basic contextual effects—peer ability, gender, and racial composition. We then interpret our main findings, show stability of within-course-professor estimates to further controls in columns 5 and 6, and discuss magnitudes.

Table 6 shows estimates of the impact of foreign students on graduating with a STEM major using the basic framework in equation (1). The outcome variable is an indicator equal to 1 if the student graduated with a STEM major within 6 years from enrollment and 0 otherwise. The explanatory

[24] The Herfindahl index is the sum of squared nationality shares. Students report more than 100 different nationalities in our data.

Table 6
Effects on STEM Graduation

	Alternative Variation			Within-Course-Professor Variation		
	(1)	(2)	(3)	(4)	(5)	(6)
A. Domestic first-term freshmen:						
Foreign share	−.023***	−.028**	−.071	−.049***	−.050***	−.047***
	(.007)	(.012)	(.121)	(.014)	(.015)	(.014)
Mean(Y)	.48	.48	.48	.48	.48	.48
R^2	.05	.05	.06	.05	.05	.10
Observations	16,828	16,828	16,828	16,828	16,828	16,828
Identifying observations (students)	13,498	9,241	1,132	7,079	7,079	7,079
Identifying classes	129	74	12	52	52	52
Identifying instructors	43	25	5	18	18	18
B. Foreign students:						
Foreign share	.009	.040	1.608***	−.002	.023	−.020
	(.013)	(.030)	(.566)	(.035)	(.039)	(.024)
Mean(Y)	.45	.45	.45	.45	.45	.45
R^2	.08	.09	.11	.09	.09	.15
Observations	3,810	3,810	3,810	3,810	3,810	3,810
Identifying observations (students)	2,880	1,698	236	1,164	1,164	1,164
Identifying classes	129	74	12	52	52	52
Identifying instructors	43	25	5	18	18	18
Fixed effects:						
Course	✗					
Professor	✗					
Term	✗	✗				
Course × term				✗	✗	✗
Course × professor		✗		✗	✗	✗
Course × professor × term			✗			
Controls:						
Peer ability	✗	✗	✗	✗	✗	✗
Peer characteristics	✗	✗	✗	✗	✗	✗
Class size					✗	✗
Individual controls						✗

NOTE.—This table displays estimates from eq. (1). Regressions include controls for course-by-term and course-by-professor fixed effects. Panel A reports results for all domestic first-term freshmen in introductory math courses. Panel B reports results for all foreign students in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Peer ability includes average standardized SAT math, SAT verbal, and high school GPA of peers. Peer characteristics include share of students from each race and share of females. Individual controls include a female indicator, race dummies, SAT math and verbal scores, and high school GPA. Standard errors in parentheses are clustered by professor. In table A2 we replicate panel A, cols. 4–6, and show coefficients for all of the included controls.
** Significant at the .05 level.
*** Significant at the .01 level.

variable of interest is the class foreign share, standardized within our sample. To facilitate comparisons we report the total number of student observations as well as the number of student observations, classes, and instructors that actually contribute to identification and are not absorbed by fixed effects. To simplify exposition, we compare variation for effects for domestic first-term freshmen in panel A. The bottom panel of the table reports the fixed effects and controls used in each column.

Column 1 includes only one-way fixed effects: course fixed effects, professor fixed effects, and term indicators. This approach is much less restrictive, leverages more variation in the data (e.g., across course-professor, across course-term), and provides more statistical power. Identification comes from 80% (13,498 of 16,828) of the total number of domestic first-term freshmen, who represent 129 out of a total of 179 classes, which are taught by 43 instructors. Larger statistical power, however, comes with the trade-off of more endogenous variation, as students are highly likely to sort across course-professor. The estimate still indicates a negative and significant relationship between foreign peers and the likelihood of obtaining a STEM degree, yet the coefficient (−0.023) is 60% smaller than that in column 4 (−0.049), indicating that such endogenous sorting may be a significant concern.

Column 2 includes course-professor fixed effects and term dummies, thereby using identifying variation from 55% of students (9,241 of 16,828) enrolled in 74 of 179 classes taught by 25 instructors. Compared with column 1, this approach reduces the scope for endogenous sorting across course-professor and also accounts for aggregate shocks/trends. However, this specification fails to account for factors varying at the course-by-term level. These may include factors such as curriculum revisions or changing course demand that may bias results. In instances when a given course is taught only by one (or a small number) of professors over time, these course-by-term factors may likely confound variation within course-professor. The column 2 estimate (−0.28) is still 43% smaller than our preferred coefficient in column 4, indicating that failure to account for such course-by-term factors may bias results.

Column 3 considers an extremely restrictive variation that includes course-by-professor-by-term fixed effects. Identification in this specification relies on professors teaching multiple sections of the same course in the same term.[25] While this perhaps is most equivalent to the ideal natural experiment—students take the same course with the same professor in the same term but experience differing levels of foreign classmates—there is a severe lack of statistical power as it is extremely uncommon for professors to teach multiple classes of the same course in a term. Identification comes from only

[25] We note that course-by-professor-by-term fixed effects are conceptually the same as a model that includes the two-way fixed effects: course-by-professor, course-by-term, and professor-by-term fixed effects. Coefficient estimates are identical, but standard errors are slightly different. The identifying variation is restricted to come only from professors who teach multiple sections of the same course in a given term. Standard errors are slightly larger when using two-way fixed effects because of the larger number of fixed effects used in estimation.

12 classes, comprising 6% of students in our sample. While we also estimate a negative coefficient, standard errors grow tremendously.

We now turn to our preferred within-course-professor variation in column 4, which includes course-by-professor and course-by-term fixed effects. Our preferred within-course-professor variation (cols. 4–6) is identified from 52 of a total of 179 introductory math courses, accounting for 42% of domestic first-term freshmen (7,079 of 16,828) in our sample. While identifying variation is reduced compared with alternatives in columns 1 and 2, we believe our preferred within-course-professor variation is advantageous, as it is demanding on exogeneity while retaining sufficient statistical power. Furthermore, our tests for exogeneity in section III increase our confidence that within-course-professor variation is truly idiosyncratic.

Column 5 adds class size as a control, and column 6 further includes individual-level control variables.[26] The coefficient estimates in panel A are stable and indicate that foreign classmates are negatively associated with the likelihood that domestic first-time freshmen eventually complete a STEM major. All estimates are statistically significant at the 1% level. Our preferred estimate comes from the fully saturated specification in column 6, which we utilize for all ensuing analysis. Results indicate that a 1 standard deviation rise in the foreign class share reduces the probability of graduating with a STEM major by 4.7 percentage points. The coefficient is roughly 10% of the mean STEM graduation rate of 48%.

By way of comparison, the magnitude of our estimate is equal in size to three-fourths of the White-Black STEM gap and one-third of the STEM gap across genders.[27] We can also size our estimates by calculating the number of students displaced for a class that has all characteristics fixed at the means in our sample—10 additional foreign students would displace 6.7 domestic freshmen, out of a total of 67 domestic freshmen STEM majors, from completing STEM degrees.[28]

[26] In table A2 we report the coefficient estimates for all control variables.

[27] Data from the National Science Foundation show that the share of bachelor's degrees earned by White students that were in STEM fields was roughly 17% in 2011. The same share for Black students was 11%. The male STEM graduation rate in 2011 was 25%, compared with only 11% for females. Hence, the White-Black STEM gap is around 6 percentage points, while the STEM gap between males and females is 14 percentage points. See https://www.nsf.gov/statistics/seind14/index\kern1pt.cfm/chapter-2/c2s2.htm#s2.

[28] The mean size of introductory math classes is approximately 217 students. If this course had the average foreign share (12.3%) and the average share of domestic first-term freshmen (approximately 65%), it would comprise roughly 26 foreign students and 141 domestic freshmen. Given that domestic freshman graduate in STEM at the mean rate of 48%, we would expect 67 STEM graduates from this group. A 1 standard deviation increase in foreign classmates amounts to roughly

Panel B considers the impact of foreign peer exposure on foreign students. Results in columns 4–6 are not statistically significant, and coefficients do not appear to be stable. This evidence suggests that foreign students do not systematically respond to increased exposure to foreign classmates. Thus, the displacement we observe for domestic freshmen is not offset by an increased likelihood of foreign students persisting in STEM.

A. Robustness Checks

Table 7 provides a series of robustness checks against various potential confounds in our analysis. All estimates are based off our preferred specification from column 6 of table 6, which includes course-by-professor and course-by-term fixed effects, and controls for peer ability, race and gender composition, class size, and individual controls. We reprint the estimate from this specification in column 1 for reference.

Column 2 ensures that our foreign peer impacts are identified from exposure in introductory math courses. Specifically, we add a control for the share of foreign classmates in all other classes taken by domestic freshmen in their first term. The results are virtually unchanged. This indicates that the transmission of foreign peer impacts on STEM major choice occurs indeed within introductory math classes, as opposed to other courses.

We reemphasize that student sorting is quite difficult at our level of variation. To sort within course-professor, students would generally have to delay enrollment in a class to a future term. For first-term freshmen, this would require delaying college. For nonfreshmen students, this could be more feasible. We provide various checks against sorting in columns 3 and 4. Column 3 examines whether there is potential sorting within course-professor based on scheduling preferences by controlling for an indicator of whether the class is offered in the morning or afternoon—we note there are a small number of classes for which the time of day was not available in our records, and so the sample size is slightly smaller.[29] Column 4 limits the

10 additional foreign students. Recall that our effect is 10% of the mean graduation rate. Multiplying 0.10 times 67 (the number of domestic students expected to graduate in STEM) yields 6.7 domestic students displaced from STEM.

[29] With respect to sorting on time of day, we first note that all introductory math classes are taught on a Monday–Wednesday–Friday schedule throughout the entire period analysis, so there is no sorting based on day of week. There are a maximum of 11 potential time slots, as classes are offered in 50-minute intervals from 8 a.m. to 7 p.m. However, in our sample there is very little variation in time of day within course-professor—i.e., professors who teach the same course repeatedly tend to keep the time slot consistent. On average professors teach in 1.9 different slots; i.e., most of them teach in at most two different time slots, and some keep the same exact slot. Considering this limited time slot variation within professor, it is hardly possible to identify specific time slot effects separately from professors fixed effects. In col. 3, we therefore control for a dummy variable indicating whether the course is offered in the morning or afternoon.

Table 7
Robustness Checks for Domestic First-Term Freshmen

	Baseline (1)	Control for Foreign Share in Other Courses (2)	Control for Morning/ Afternoon Dummy (3)	Calculus I Only (4)	Use First-Term Freshmen Foreign Share (5)	Control for Nationality Herfindahl Index (6)
Foreign share	−.047***	−.048***	−.033***	−.037*		−.039**
	(.014)	(.014)	(.010)	(.019)		(.016)
First-term freshmen foreign share					−.037	
					(.029)	
Mean(Y)	.48	.48	.48	.42	.48	.48
Observations	16,828	16,828	16,636	7,031	16,828	16,828
R^2	.10	.11	.10	.07	.10	.10

NOTE.—This table displays estimates from eq. (1). Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor.

* Significant at the .10 level.
** Significant at the .05 level.
*** Significant at the .01 level.

sample to only Calculus I courses, where the large majority of students are first-term freshmen (see table 1) and thus where endogenous sorting of nonfreshmen students may pose less of a threat. Results from both of these checks remain robust and statistically significant, although column 4 loses some precision because of the 40% reduction in sample size.

Finally, column 5 and 6 examine whether the presence of foreign student information networks biases our estimates. Column 5 replaces the explanatory variable of interest (i.e., the overall foreign peer share) with the share of peers who are foreign first-term freshmen. As first-term freshmen are entirely new to the university, they may be less able to leverage information networks. While the estimated magnitude is similar to our baseline, using only foreign first-term freshmen reduces our foreign share variation. As a result, estimates become more imprecise. Column 6 controls for the nationality-based Herfindahl index, described in section III, to account for the presence of foreign student information networks. Results remain robust and significant.

B. Non-STEM Degrees and Expected Earnings

Having established the robustness of our results on STEM graduation to various concerns, we now examine where domestic students who were displaced from STEM ended up. Table 8 uses our preferred specification from column 6 of table 6 and examines alternative outcomes. Column 1 reprints our main effect on STEM graduation for reference. Columns 2 and 3 examine the likelihood of completing a social science or arts and humanities

Table 8
Effects on Graduation Outcomes and Expected Earnings

	Graduate STEM (1)	Graduate SS (2)	Graduate AH (3)	Drop Out (4)	Earn 0 (5)	Earn 6 (6)	Earn 11–15 (7)	Earn 26–30 (8)
Foreign share	−.047***	.041**	.0100*	−.0058	.036	.031	.031	.028
	(.014)	(.016)	(.0056)	(.012)	(.089)	(.087)	(.086)	(.083)
Mean(Y)	.48	.27	.076	.18	8.83	9.39	9.65	9.72
Observations	16,828	16,828	16,828	16,828	16,828	16,828	16,828	16,511
R^2	.10	.06	.03	.06	.06	.06	.06	.06

NOTE.—This table displays estimates from eq. (1). Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Expected earning in cols. 5–8 have been assigned to each student on the basis of his or her graduation major. Earnings estimates come from calculations done by the Brookings' Hamilton Project and refer to median earnings calculated using US Census Bureau ACS data at different years after college graduation. Standard errors in parentheses are clustered by professor. AH = arts and humanities; SS = social science.
* Significant at the .10 level.
** Significant at the .05 level.
*** Significant at the .01 level.

degree, respectively. Column 4 examines the likelihood of dropping out. The decline in graduating with a STEM major is primarily offset by increases in graduating with a social science major. A 1 standard deviation increase in foreign classmates is associated with a 4.1 percentage point increase in the likelihood of graduating with a social science major. There also is a small positive impact on graduating in arts and humanities, while there is no discernible impact on dropping out.

Since STEM graduates earn more on average than non-STEM graduates,[30] a decline in the probability of STEM graduation might be expected to negatively impact earnings of the domestic students. However, the aggregation of outcomes into three groups (STEM, social science, and arts and humanities) may mask heterogeneity within STEM and non-STEM majors as well as potentially important margins of adjustment. For example, displacement from a high-earning STEM major to a low-earning social science major carries far different implications than displacement from a low-earning STEM major to a high-earning social science major.

Lacking data on actual earnings, we link each student's major at graduation (we observe 151 different majors of graduation in our data) to measures of the expected earnings for that major and use log earnings as the outcome variable.[31] Major-specific expected earnings provide an alternative way to measure of the relevant qualities and characteristics of each major and may reveal intricacies not detectable when splitting by subject matter into STEM, social science, and arts and humanities. While expected earnings may be useful, we also caution that average earnings presumably masks substantial heterogeneity within college major and acknowledge that this limits our ability to characterize marginal students.

Results are shown in columns 5–8 of table 8. Estimates are positive, possibly suggesting that foreign classmates may induce domestic students to choose non-STEM majors with higher expected earnings, but small and very imprecisely estimated. Standard confidence intervals do allow us to rule out large negative impacts on expected earnings, and hence it is not the case that domestic students are systematically displaced from STEM majors with very high expected earnings to non-STEM majors with low expected earnings.[32]

[30] In our data, expected earnings of STEM graduates 11–15 years after graduation are 22% higher than those of non-STEM graduates.

[31] These measures are provided by the Hamilton Project (Hershbein and Kearney 2014) and estimated using ACS data. Data include estimates for initial earnings and earnings at 6, 11–15, and 26–30 years after graduation. Dropouts are assigned the average earnings of students with some college who did not complete a degree. More details about these data are reported in sec. II.

[32] Section B of the appendix presents a graphical analysis of the major counterfactual dynamics underlying the null effect of foreign share on expected earnings.

C. Impacts on STEM Occupation

Graduation in a STEM degree is a strong correlate for entry into STEM occupations, as fewer than 9% of all individuals with a college degree in a non-STEM field report working in a STEM occupation.[33] Displacement from STEM majors would naturally be expected to also reduce the probability of working in a STEM occupation, but not for certain. For example, if every student displaced from a STEM major would have counterfactually worked in a non-STEM job, we should find no effect on the likelihood of working in a STEM occupation. At the other extreme, if every student displaced from a STEM major would have counterfactually worked in a STEM job, the effects of working in a STEM occupation and graduating with a STEM major should be identical. Hence, conditional on there being displacement from STEM majors, understanding to what extent foreign classmates have long-run impacts on occupational choice still requires empirical investigation.

We utilize individual data on actual occupations of students and estimate our baseline specification, replacing the outcome with indicator variables for working a STEM or non-STEM occupation. Because we are unable to link occupational data to all students, we first ensure that the likelihood of finding an occupation link is not endogenously related to the foreign classmates exposure. This check is performed in column 1 of table 9, where the outcome is an indicator variable equal to 1 if occupational records were matched to the student and 0 if no match was found. The results assure that the sample of students containing occupational information is not endogenously selected.

We examine whether foreign classmates affect the likelihood of working in a STEM occupation after college in column 2. Results indicate that a 1 standard deviation rise in the foreign class share lowers the probability of working in a STEM occupation by 2.6 percentage points. The estimate is statistically significant and is 6% of the mean probability of working in a STEM occupation (43%). The results indicate that the impact of foreign classmates has implications for educational attainment (STEM major) and STEM career paths. We caution, however, that our matching process is imperfect and that having a binary dependent variable necessarily indicates the presence of nonclassical measurement error. For measurement error to entirely explain our findings, however, would require that the difference in mean covariates of false positives and false negatives, weighted by their probabilities in the sample, be quite large (Meyer and Mittag 2017).

Similar to our exercise using expected earnings for each major, we utilize occupation-specific earnings to better characterize the nature of displacement

[33] Authors' tabulations from individuals age 30 and under, reporting both college major and occupation in the 2009–16 ACS.

Table 9
Effects on STEM Careers and Occupation-Based Expected Earnings

	Matched = 1 (1)	STEM Occupation = 1 (2)	Individual Income (3)	Family Income (4)	Wage (5)
Foreign share	.0034	−.026***	−.0042	−.012	−.0060
	(.0097)	(.0076)	(.0098)	(.012)	(.0095)
Mean(Y)	.75	.43	11.0	11.8	10.9
Observations	16,828	12,482	12,482	12,482	12,482
R^2	.41	.03	.02	.01	.02

NOTE.—This table displays estimates from eq. (1). Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Expected income and earnings in cols. 3–5 have been assigned to each student on the basis of his or her observed occupation title. Expected earnings and income are estimated for each SOC occupation code using the most recent ACS data on a sample that mimics the characteristics of individuals in our administrative data. Standard errors in parentheses are clustered by professor.
*** Significant at the .01 level.

from STEM occupations.[34] Columns 3–5 of table 9 use the log of occupation-specific average individual income, family income, and average wage, respectively, as outcomes. Coefficient estimates are negative, imprecisely estimated, and very small in size. These results indicate that domestic students are not displaced into significantly lower-paying non-STEM occupations—they appear to be choosing occupations that have very similar earning power relative to the STEM occupations from which they are displaced.

In sum, we find that foreign peers reduce the likelihood that domestic students complete STEM degrees. Domestic students respond by switching to social sciences. While these effects result in persistent long-run reductions in the likelihood of working in STEM occupations, they do not appear to have detrimental impacts on expected earnings. We now examine heterogeneity in effects to better characterize marginal students and inform our investigation of potential underlying mechanisms.

D. Baseline Ability

To further understand STEM displacement, we assess whether effects differ by baseline STEM ability, as marginal students might be those with relatively low baseline STEM ability. For each domestic student, we construct measures of both absolute ability and comparative ability in STEM. Individuals with high/low STEM ability are those with high/low SAT math

[34] Specifically, using the 2014–16 ACS we calculate average earnings/income measures for college-educated native-born workers from the same birth cohorts as those observed in our student data. We then match these earnings/income measures to students according to their observed occupation.

scores relative to the average SAT math score of their cohort. Individuals with high/low comparative ability in STEM are those who have a relative SAT math score (i.e., SAT math score relative to the average SAT math score or their cohort) that is higher/lower than their relative SAT verbal score. To uncover heterogeneity, we use local linear regression to estimate the effects on STEM graduation at each percentile of the absolute and comparative advantage measures.[35]

Figure 4*A* plots coefficients from our main specification and shows that students with low comparative advantage in STEM (low percentiles) experience relatively stronger displacement. The bottom third of students have an average coefficient of −0.07, while for the top third it is −0.02. However, a parametric test for heterogeneous effects by tertiles does not show evidence of a statistically significant difference. Hence, we view this as suggestive evidence that students with weaker comparative advantage in STEM fields (higher comparative advantage in non-STEM) might be those most at risk of displacement.

Figure 4*B* presents local linear regression estimates to see whether effects differ on the basis of a measure of absolute advantage.[36] There is little difference in the effect for domestic students with high and low absolute STEM ability. All point estimates are contained within the confidence interval for all others. Using this measure, we cannot reject that students with differing absolute STEM ability are equally displaced from STEM.

E. Race and Gender

Table 10 explores heterogeneity across different types of domestic students. Each estimate represents a separate regression using our preferred specification. Research on the gender gap in STEM education has uncovered various factors, such as confidence and role models, as important for the retention of female students (e.g., Gneezy, Niederle, and Rustichini 2003; Niederle and Vesterlund 2007; Carrell, Page, and West 2010). We assess whether foreign classmates may more strongly affect domestic females

[35] To construct our measure of comparative advantage, we separately standardize students SAT math and verbal scores at the cohort level to have mean 0 and standard deviation 1. Then, students are ranked on the basis of the difference in their standardized math and verbal test scores. Local linear regressions of eq. (1) are estimated at every percentile using a 1 standard deviation bandwidth and Epanechnikov kernel weighting, and 95% confidence intervals are constructed from 250 bootstrapped repetitions, sampled at the class (i.e., math lecture) level.

[36] To measure absolute advantage, we estimate the ex ante likelihood that a student will graduate with a STEM major. We regress STEM graduation on all background characteristics (gender, race, SAT, etc.) and year fixed effects. We then use the regression coefficients to predict each student's likelihood of graduating with a STEM major. Our measure is relatively simple but represents the type of prediction policy makers or education administrators may use when trying to determine what factors lead to STEM persistence.

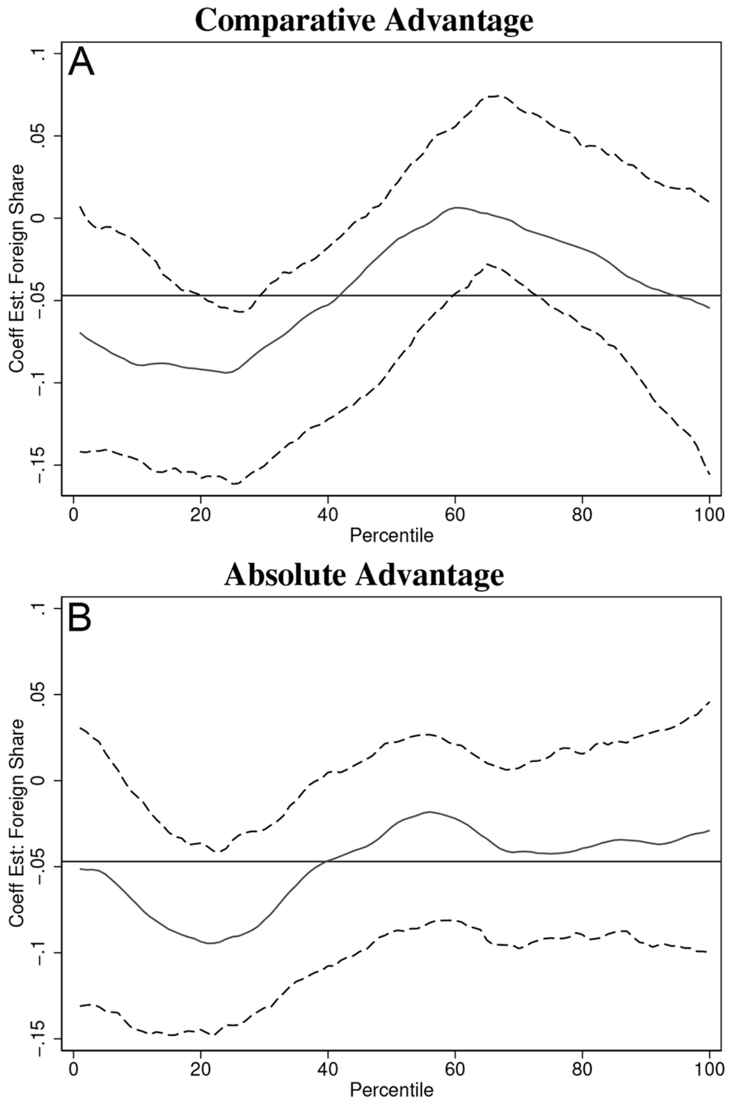

FIG. 4.—Local linear regression results. Results show coefficient estimates from local linear regressions of equation (1) with STEM graduation as the outcome. Domestic first-term freshmen in our core sample are ranked from 1 to 16,828 on the basis of a measure of comparative advantage (*A*) and absolute advantage (*B*). Lower percentile represents lower inclination toward STEM. Each graph plots 99 estimates from local linear regression centered at each percentile using Epanechnikov kernel weighting. Confidence intervals (dashed lines) are derived from the 5th and 95th percentiles of 250 bootstrapped estimations, resampled at the course level. See text for details on the calculation of comparative and absolute advantage. The horizontal solid line shows the mean effect from column 6 of table 6.

Table 10
Effects on Different Domestic Groups

	Female (1)	Male (2)	White (3)	Asian (4)	Minority (5)	First Major STEM (6)	First Major Not STEM (7)
Graduate STEM	−.02	−.07***	−.04**	−.09***	−.01	−.04***	−.04***
	(.02)	(.02)	(.01)	(.02)	(.03)	(.01)	(.02)
Graduate social sciences	−.00	.09***	.03	.06***	.02	.03***	.05*
	(.02)	(.02)	(.02)	(.02)	(.03)	(.01)	(.03)
Graduate arts and humanities	.02**	−.00	.01	.01*	.05***	.01*	.01
	(.01)	(.01)	(.02)	(.00)	(.02)	(.01)	(.03)
No graduation	.00	−.02	−.01	.02***	−.06*	−.00	−.02
	(.01)	(.02)	(.02)	(.01)	(.04)	(.01)	(.02)
Earn 0	−.02	.12	.07	−.17**	.50*	.02	.12
	(.06)	(.16)	(.12)	(.07)	(.28)	(.09)	(.14)
Earn 6	−.02	.10	.06	−.17***	.49*	.02	.10
	(.06)	(.16)	(.12)	(.06)	(.28)	(.09)	(.14)
Earn 11–15	−.02	.10	.06	−.17***	.49*	.02	.10
	(.06)	(.15)	(.12)	(.06)	(.28)	(.09)	(.14)
Earn 26–30	−.03	.10	.06	−.16***	.46*	.02	.09
	(.06)	(.15)	(.12)	(.06)	(.25)	(.09)	(.13)
Observations	8,155	8,356	6,343	7,533	1,585	12,419	4,092
R^2	.07	.07	.05	.07	.17	.07	.08

NOTE.—This table displays estimates from eq. (1). Outcomes for different subgroups are reported across the columns. Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor.
* Significant at the .10 level.
** Significant at the .05 level.
*** Significant at the .01 level.

relative to males. The first two columns show that females are not strongly impacted by foreign classmates. Instead, the reduction in STEM primarily comes from domestic male students.

In columns 3–5, we stratify on domestic students' race/ethnicity. Similar to the gender gap in STEM, the minority gap in STEM has also received much academic attention. Our results show that foreign peers have negative impacts on the likelihood of graduating with a STEM major for all race groups, although for minorities (Blacks and Latinos) estimates are imprecise. An interesting insight is that minorities are more likely to stay in school and graduate, which leads to positive and significant effects on expected earnings, in both the short run and the long run. We note that this result is consistent with Arcidiacono, Aucejo, and Hotz (2016), who find that minority students at highly ranked institutions may be more likely to have graduated with a STEM degree if they instead attended less-competitive, lower-ranked institutions. In our setting, foreign peers in the classroom appear to indirectly induce minority students to stay in school by choosing less competitive majors. Whites and Asians are strongly displaced from STEM majors, similar to Borjas (2004), and gravitate toward social science. In contrast to minorities, Asian students also are more likely to drop out, which in turn results in significant negative impacts on expected earnings.

F. Initial Major Choice

To better characterize the nature of our effects, we assess whether results are more consistent with STEM majors being displaced out of STEM or non-STEM/undeclared majors being less likely to switch into STEM fields. Columns 6 and 7 of table 10 examine differences in effects between students who declared a STEM major by the end of the first term and those who did not (i.e., either declaring a non-STEM major or remaining undeclared). We note that our data contain majors only at the end of the first term of enrollment and not before. While we stratify on the major reported by the end of the first term, we also caution that this is in itself an outcome. Nonetheless, there does not appear to be an apparent difference between students who declare STEM early and those who do not—both groups experience sizable displacement from STEM majors and into social sciences.

VI. Exploring Mechanisms

Why do foreign classmates lead to lower STEM completion among domestic students? We hypothesize four mechanisms. First, displacement might be the result of competition that lowers grades and hence leads students to abandon STEM majors. This might happen in classes with "curved" grading if foreign students perform relatively better than domestic students in these courses. Given that declaring a STEM major requires obtaining grades in introductory math courses above a certain threshold, if marginal domestic students obtain lower scores as a result of more competition when the share of foreign students in those classes is higher, they might be systematically displaced from STEM majors.

Second, changes in the communicative environment within classrooms following the entry of many nonfluent English speakers may reduce the scope for knowledge spillovers that arise from questions asked during lecture or from peer-to-peer interaction. Alternatively, instructors may respond by altering the delivery of the course, thereby affecting students' relative learning and or enjoyment.

Third, foreign classmates in introductory math classes may provide students with a local assessment of their relative ability. As the introductory math class is often the first STEM class that students take, they may perceive their relative ability in that class as a signal of their ranking among all STEM majors. As foreign students have a comparative advantage in STEM relative to non-STEM fields, their presence may lead domestic students to update their perceptions of how their own comparative advantage in STEM ranks among other students.

The fourth mechanism we explore is simple distaste. If domestic students do not enjoy the presence of foreign students and/or update their beliefs about the presence of foreign workers in STEM occupations based on the foreign share observed in the introductory math courses, they may seek alternate classes or majors by means of avoidance.

A. Competition in Introductory Math Courses

We examine whether domestic students are displaced from STEM majors because of competition from foreign peers. This could manifest in several ways. Domestic students might have a higher likelihood of dropping the course or may receive lower grades if they remain enrolled.

Panel A of table 11 examines whether foreign peers impact the likelihood of withdrawing from the course. Positive effects would indicate that students select out of math very soon after meeting their classmates. Overall, results indicate that females and White students are induced to drop the course. Results for other groups are not statistically significant. We note that while withdrawal could signal competition, it could also be due to other reasons, such as preferences against learning with foreign peers. We return to this discussion later when we formally examine preferences in section VI.D.[37]

Panel B examines the impact on grades, which we standardize within the class to have mean 0 and standard deviation 1, conditional on remaining in the class. While the overall results in column 1 do not reveal grade effects, column 4 shows significant negative impacts on grades for White students—a 1 standard deviation increase in foreign peers reduces grades by a tenth of a standard deviation. Panel C examines a different measure of academic performance—the likelihood of receiving a grade above the median. While overall grade effects are useful to study, they may mask marginal changes. In particular, one margin of adjustment that would be relevant in our setting would be receiving the minimum grade sufficient for progression in the STEM major. Because majors vary in grade cutoff scores required for progression, we use above and below median as a rough indicator of one's ability to progress. Interestingly, results show that White students are also less likely to score above the median. As such, displacement of White students from STEM majors may be driven by lower grades and, in particular, reducing grades below the sufficient threshold for progression in the major.

[37] In specifications not shown, we also separately examined immediate withdraws (one week or less into a course) and late withdraws (likely after receiving graded work) and found no significant effects.

Table 11
Effects on Performance in Introductory Math Courses

	All (1)	Female (2)	Male (3)	White (4)	Asian (5)	Minority (6)
A. Drop course:						
Foreign share	.02	.04**	−.01	.03*	.01	−.01
	(.02)	(.02)	(.01)	(.01)	(.02)	(.05)
Mean(Y)	.11	.12	.11	.09	.12	.17
Observations	16,828	8,353	8,475	6,482	7,666	1,606
R^2	.05	.06	.07	.05	.08	.14
B. Standardized grade:						
Foreign share	−.01	.00	−.02	−.10***	.03*	.16
	(.02)	(.03)	(.03)	(.03)	(.02)	(.10)
Mean(Y)	.17	.21	.12	.21	.19	−.10
Observations	14,799	7,284	7,515	5,865	6,671	1,328
R^2	.22	.24	.21	.24	.21	.29
C. Top 50%:						
Foreign share	−.02	−.02	−.02	−.08***	.01	.01
	(.02)	(.02)	(.03)	(.03)	(.03)	(.04)
Mean(Y)	.67	.70	.65	.69	.68	.57
Observations	14,799	7,284	7,515	5,865	6,671	1,328
R^2	.17	.19	.17	.19	.17	.27
D. Switch out STEM:						
Foreign share	.04***	−.00	.07***	.06***	.05***	.04
	(.01)	(.02)	(.02)	(.02)	(.01)	(.04)
Mean(Y)	.42	.42	.42	.41	.40	.54
Observations	12,536	5,889	6,647	4,854	5,673	1,226
R^2	.10	.11	.11	.10	.11	.22
E. Time to final major declaration:						
Foreign share	.10	−.15	.32*	.23	.22	.14
	(.12)	(.11)	(.19)	(.18)	(.17)	(.38)
Mean(Y)	5.05	5.24	4.86	4.89	5.18	5.00
Observations	16,828	8,353	8,475	6,482	7,666	1,606
R^2	.04	.04	.05	.05	.06	.09

NOTE.—This table displays estimates from eq. (1). Outcomes for different subgroups are reported across the columns. Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. Different outcomes are reported in the panels. Panel A examines whether an individual withdrew from the class. Panel B examines the standardized grade earned, conditional on staying in the class. Panel C examines the likelihood of earning a grade above the median. Panel D examines whether individuals ever made a switch from STEM to non-STEM. Panel E examines the time, in terms, to declare one's final major. The foreign share is standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor.
* Significant at the .10 level.
** Significant at the .05 level.
*** Significant at the .01 level.

We also examine other shorter-run outcomes in panels D and E. Specifically, in panel D we examine whether students ever made a switch out of a STEM major, conditional on declaring STEM early before or during their first term of university attendance. The results helps us better characterize that the marginal student was one who otherwise would have majored in

STEM but switched out of STEM because of foreign peer exposure in their introductory math class. This contrasts with non-STEM majors who would have switched into STEM majors. Panel E also examines whether foreign peers affect the time to form their final major decision, measured in academic terms. The idea is to track whether foreign peers' displacement delays domestic students' major choice. This would be consistent with domestic students requiring time to decide the alternative major once they decide to abandon their STEM option. Results do not show a strong pattern of effects on time to declare the final major. For White students, the coefficient is marginally significant but rather small in magnitude—a 1 standard deviation increase in foreign peers increases the time to declare a major by a third of a term, which is roughly one month.

B. English Communication

Descriptive studies and surveys about foreign student integration in US education have emphasized their lower levels of English proficiency (Erisman and Looney 2007) and subsequent reticence and hesitance to communicate within classroom settings (e.g., Horwitz, Horwitz, and Cope 1986; Rodriguez and Cruz 2009; Stebleton, Huesman, and Kuzhabekova 2010; Stebleton 2011; Yamamoto and Li 2012).[38] Lower levels of communication may reduce positive externalities arising from peer-to-peer or peer-to-instructor interaction. Lower English language ability may lead instructors to alter the pace or style of instruction or substitute time away from helping domestic students toward helping foreign students (Diette and Oyelere 2012; Geay, McNally, and Telhaj 2013).

To empirically assess this concern, we examine whether effects are driven by foreign classmates with low levels of English proficiency. Primarily, we categorize foreign students as having relatively "low" or "high" proficiency on the basis of whether their SAT verbal score falls below or above the median score of all foreign students in their cohort. We then repeat regressions of equation (1), splitting the overall foreign share in the class into the shares with high and low fluency.

The results from this exercise are reported in panel A of table 12. The displacement from STEM is larger for domestic students who experience increases in foreign classmates with low fluency. A 1 standard deviation rise in the share of low-fluency classmates reduces the likelihood of completing STEM majors by 5.3 percentage points. An equivalent increase in classmates with high fluency has no significant effect. classmates with low fluency displace domestic students primarily toward social science but partially also toward arts and humanities. In columns 5 and 6, we test whether the

[38] An extensive report on foreign individuals in higher education (Erisman and Looney 2007) found that 66% of foreign students indicated that English was not their primary language.

Table 12
Testing the Communication Mechanism—Foreign Classmates' Fluency

	Graduate STEM (1)	Graduate SS (2)	Graduate AH (3)	Drop Out (4)	Standardized Grade (5)	Above 50th Percentile (6)
Foreign share low fluency	−.053**	.060***	.016***	−.023	−.008	−.032
	(.023)	(.018)	(.006)	(.015)	(.025)	(.020)
Foreign share high fluency	−.006	−.008	−.003	.015	−.000	−.011
	(.023)	(.030)	(.005)	(.015)	(.028)	(.027)
Mean(Y)	.48	.27	.08	.18	.17	.60
Observations	16,828	16,828	16,828	16,828	14,799	16,828
R^2	.10	.06	.03	.06	.22	.17

NOTE.—This table displays estimates from eq. (1), where the foreign share is separately calculated for those with above-median SAT verbal scores (i.e., "high fluency") and those with below-median SAT verbal scores (i.e., "low fluency"). Different outcomes are reported across the columns. Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. The foreign shares are standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor. AH = arts and humanities; SS = social science.
** Significant at the .05 level.
*** Significant at the .01 level.

effects on grades that were statistically detectable for White students in table 11 are amplified when interacted with the language mechanism. While the effect of a higher share of low-fluency classmates on the probability of getting a grade above the median is marginally not significant (p-value of .10), its magnitude is larger than for the effect of the overall share of foreigners. Overall, this constitutes weak evidence for a direct role of reduced classroom communication in affecting domestic students' performance in introductory math courses. Therefore, the effect of the language mechanism on major preferences is likely taking place through other potential channels, for instance, the overall introductory math course enjoyment/experience.

In the appendix, we explore this communication/interaction channel further by exploring whether the impact of foreign classmates with low English fluency is exacerbated/limited by the English proficiency of instructors. In particular, native-English-speaking professors might be more equipped to alter the pace of instruction to compensate for lower levels of classroom communication. Foreign professors with less English fluency may reduce peer-to-instructor interaction even further. With the important caveat that domestic and foreign students might endogenously select instructors, table A3 shows results where the shares of foreign classmates with high and low English fluency are interacted with indicators for whether the instructor is a native English speaker. These estimates show that in courses with a native-English-speaking instructor, the heterogeneous effect of foreign peers' English proficiency is neutralized, although the displacement effect remains on average. This suggests that native-English-speaking instructors might indeed be able to compensate for lower levels of communication in the classroom. To the contrary, foreign instructors appear to polarize and magnify the heterogeneous effect of foreign peers' English proficiency on domestic students' major choice, with a large and precise displacement effect in classes with a high share of low-proficiency foreign peers and a positive effect in classes where the foreign peers can better communicate with classmates and the instructor.

Overall, these results constitute suggestive evidence that foreign classmates with lower levels of English ability might drive the displacement from STEM. While we cannot pin down the reason for why this is the case, our working hypothesis is that the communicative environment within classrooms is altered when the foreign peers have low English proficiency. Reduced communication within classrooms may result in diminished social interactions and/or missed peer-to-peer and peer-to-instructor exchanges, which are essential components of effective learning and of an enjoyable social experience. While our analysis offers firsthand evidence of the potential role of communication within the class, further research is required to provide more rigorous evidence of the linguistic dynamics of foreign peers in the classroom.

C. Relative Ranking in STEM

The movement of domestic students away from STEM fields may be a response to a signal that alters one's perceived relative ability ranking in STEM. Related literature has shown that rankings matter substantially for educational choices and outcomes (Elsner and Isphording 2017; Cicala, Fryer, and Spenkuch 2018; Murphy and Weinhardt 2020). In response to foreign peers, who may change relative STEM rankings within a classroom, individuals may switch to fields of study or occupations that are less quantitative in nature and more communication intensive, in accordance with the theory of comparative advantage (Peri and Sparber 2009, 2011). In our context, domestic students may perceive that their comparative advantage in STEM fields falls with more foreign classmates and respond accordingly by switching to non-STEM majors.

We use SAT math and verbal scores to proxy for individual ability in STEM and non-STEM fields, respectively, as they have been shown to predict STEM and non-STEM major choice (Turner and Bowen 1999)[39] To measure the ability of each individual in STEM and how they rank relative to their classmates, we utilize a traditional approach aimed at identifying

[39] Turner and Bowen (1999) documented that SAT verbal scores are associated with a higher likelihood of majoring in non-STEM—in particular, humanities fields—especially when SAT math scores are low. They also show a similar association for SAT math scores—higher SAT math scores are correlated with a greater likelihood of majoring in STEM.

individual comparative advantage (Sattinger 1975). We define individual's ability in STEM relative to their cohort by calculating the distance in standard deviations of the individual's SAT math score from the average SAT math score of their cohort (which is standardized to zero). Our measure of comparative advantage in STEM is then the difference between an individual's relative ability in STEM and non-STEM. We refer to this as "cohort-level comparative advantage." The summary statistics presented in table 2 indicate that foreign students possess a comparative advantage in STEM fields. Their relative SAT math to verbal score is higher than that of domestic freshmen.[40]

We then also construct measures of comparative advantage within the individual's introductory math class by comparing individual ability relative to the class SAT averages rather than the cohort averages, which we refer to as "class-level STEM comparative advantage" (CSCA).[41] This allows us to first measure whether exposure to foreign classmates in introductory math classes actually provides a different signal of an individual's ranking in STEM in the classroom relative to their actual ranking in the cohort. Column 1 of table 13 performs this check. We utilize our baseline specification and replace the dependent variable with the measure of an individual's CSCA. Additionally, we also control for the cohort-level comparative advantage, so that regressions are identified from individuals with the same cohort-level comparative advantage but different exposure to foreign classmates. Results indicate that foreign students drive down the average CSCA ranking of domestic students relative to their position in the cohort.[42]

Column 2 offers descriptive evidence that the CSCA is on average positively correlated with the probability of graduating in STEM. Column 3 combines these two pieces of evidence to test whether the interaction of a higher share of foreign peers with a lower CSCA drives STEM displacement effects—that is, whether students who face a higher share of foreign peers and have a low CSCA, holding their cohort STEM comparative advantage constant, are more likely to be displaced. The interaction coefficients of column 3 indicate that the displacement effect of foreign peers is not heterogeneous across different CSCA quartiles. Hence, we conclude that

[40] The comparative advantage of foreign students in STEM is unlikely to be institution specific—foreign college-educated individuals in the labor market are highly overrepresented in STEM fields and STEM majors (Gambino and Gryn 2011; Peri, Shih, and Sparber 2015).

[41] Our measure is similar to the measure of the degree of misinformation of ranking from Murphy and Weinhardt (2020), whereby the classroom ranking is a local measure that may not reflect one's ability in the cohort.

[42] This specification still holds individual and peers' SAT math and SAT verbal constant. This means that domestic students with same ability in courses with similar overall average ability can have very different within-class comparative advantage standings according to the foreign share in the course.

Table 13
Comparative Advantage Mechanism

	CSCA (1)	Graduate STEM (2)	Graduate STEM (3)
Foreign share	−.063***		−.039***
	(.023)		(.013)
CSCA quartile = 2		.026*	.015
		(.014)	(.015)
CSCA quartile = 3		.037*	.021
		(.019)	(.020)
CSCA quartile = 4		.055**	.026
		(.026)	(.027)
CSCA quartile = 2 × foreign share			−.002
			(.011)
CSCA quartile = 3 × foreign share			−.013
			(.011)
CSCA quartile = 4 × foreign share			−.017
			(.013)
Mean(Y)	−.02	.48	.48
Observations	16,828	16,820	16,828
R^2	.99	.10	.11
Controls:			
High school GPA	✗	✗	✗
SAT math and verbal		✗	✗
STEM cohort comparative advantage	✗	✗	✗
Peer characteristics	✗	✗	✗
Class size	✗	✗	✗
Individual controls	✗	✗	✗

NOTE.—This table displays estimates from eq. (1). In col. 1 the dependent variable is a measure of within-class comparative advantage in STEM. In cols. 2 and 3 we replicate our main specification separately for students who had a drop in the second, third, and fourth quartiles of the within-class comparative STEM advantage measure (with respect to their own university-level comparative advantage), with the first quartile being the omitted category. Regressions include controls for course-by-term and course-by-professor fixed effects, peer ability (i.e., average standardized SAT math, SAT verbal, and high school GPA of classmates), peer characteristics (i.e., share of students from each race and share of females), class size, and individual controls (i.e., a female indicator, race dummies, SAT math and verbal scores, and high school GPA). Results are for domestic first-term freshmen in introductory math courses. The foreign share is standardized to have mean 0 and standard deviation 1. Standard errors in parentheses are clustered by professor. CSCA = class-level STEM comparative advantage.
* Significant at the .10 level.
** Significant at the .05 level.
*** Significant at the .01 level.

mechanical effects of foreign peers on the class comparative advantage in STEM of domestic students are unlikely to be an operative mechanism. This finding is also consistent with Murphy and Weinhardt (2020), who find that local (classroom) ranking signals/information are generally less likely to be important when optimizing future effort and other educational decisions.

D. Social Preferences

A final reason for displacement may be due to preferences over peers in the classroom. Distaste for studying alongside foreign classmates would manifest in domestic students avoiding them in future courses. We replace the dependent variable in equation (1) with the share of foreign classmates in all classes taken in following terms. We perform this analysis for up to nine terms (i.e., three academic years, where one academic year consists of three terms), since many students graduate or drop out of the sample after 3 years.

The results of this exercise are shown in figure 5. Point estimates are indicated by the points, and 95% confidence intervals are provided for reference. The vertical axis measures the effect of a 1 standard deviation increase in the share of foreign classmates in introductory courses on the share of foreign classmates in all classes in future terms. Results in figure 5*A* indicate no overall pattern of avoidance of foreign students.

In figure 5*B* we assess whether rigid course sequences for STEM majors may constrain their ability to avoid foreign peers. We therefore focus on

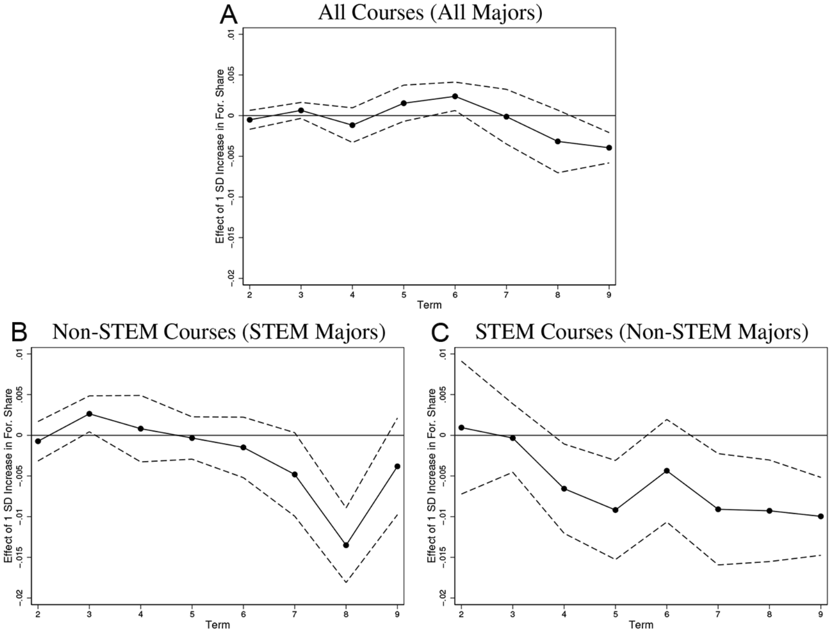

FIG. 5.—Effect of introductory math foreign share on foreign share in future courses. Results show coefficient estimates from regressions of equation (1) with the outcome being the share of foreign classmates in all classes in each term after the first. *A* shows the effect on future exposure in all classes. *B* limits the sample to students reporting a STEM major at the end of their first term and shows the effects on future exposure in non-STEM courses only. *C* limits the sample to students reporting a non-STEM major at the end of their first term and shows the effects on future exposure in STEM courses only. For reference, 95% confidence intervals are provided. We show results up to 12 terms out, which represents 4 years, as many students graduate and leave the sample after 4 years.

the share of foreign classmates in all non-STEM classes for domestic students who declared a STEM major during the first term of university attendance. STEM majors may find it easier to select out of classes with many foreign peers when they are non-STEM and likely elective courses. Figure 5*B* shows that domestic STEM majors show no systematic avoidance of foreign students in future non-STEM courses.

To complete the analysis, we provide an analogous graph in figure 5*C*, which focuses on the future foreign share in STEM classes chosen by domestic students who did not declare a STEM major during their first term of university attendance. In this case, there is a negative effect of foreign peer composition in introductory math courses on future courses' foreign share, which shows up from the second year of university attendance. While this evidence might reflect actual avoidance behavior, we cannot exclude alternative explanations. For instance, students displaced might develop an aversion for math-intensive courses and therefore choose easier-to-pass elective STEM courses, which happen to be less attended by foreign peers.

VII. Conclusion

Disinterest in STEM education has generated concern over whether the United States will have sufficient numbers of STEM workers. At the same time, globalization has increased the number of foreign students in higher education institutions. This paper explores whether the presence of foreign students in college affects the likelihood that domestic students obtain STEM degrees and eventually work in STEM occupations.

Using administrative records from a large US research university, we find that higher exposure to foreign classmates in the first-term introductory math course reduces the likelihood that domestic students eventually complete a STEM degree and pursue a STEM career. Displaced domestic students adjust by moving to social science majors. Displacement does not appear to substantially harm the earnings of domestic students, as they gravitate toward social science majors/occupations with equally high earning power.

We follow the peer effects literature exploiting the natural variation in cohort composition across time within schools (e.g., Hoxby 2000; Carrell and Hoekstra 2010; Anelli and Peri 2019) and focus on that within course-professor groups to estimate the causal impact of foreign classmates. We argue, with empirical support from exogeneity tests, that there is idiosyncratic cohort-to-cohort variation in the number of foreign peers enrolling in introductory math courses conditional on course and instructor. Our results are identified from idiosyncratic variation in foreign peers within courses taught by the same professor over time. This leaves open a narrow potential channel of endogenous student sorting on unobservables across years, and we encourage future studies to use fully randomized assignment to courses.

We test several potential channels spanning from direct competition effects to within-class communication, signal updating, and discriminatory preferences. We find suggestive empirical evidence that changes to the communicative environment within the classroom might play the main role in generating displacement. Foreign students with low levels of English proficiency may be less likely to engage in communication in the class, leading to fewer productive peer-to-peer and instructor-to-peer interactions. Corroborating analysis finds that foreign students who possess weak English language skills appear to have much stronger impacts than those who are fluent in English.

If the role of the communication channel is confirmed by further research, our study generates implications for interventions aimed at preventing attrition from STEM majors. Interventions that improve or facilitate interaction and communication of foreign students (e.g., compulsory attendance of precollege English courses) may help improve peer-to-peer learning and instructor-to-peer interaction. Alternatively, distributing foreign students with very low English fluency more homogeneously across courses and avoiding their concentration in courses taught by foreign instructors might reduce the negative impact on the overall class communicative environment.

Although this study was performed using data from a single university, our findings carry implications for aggregate welfare. Increasing numbers of foreign students—who have an unconditionally higher propensity to graduate with STEM majors—are unlikely to increase the future STEM labor supply, as domestic students are displaced to non-STEM fields. Moreover, given that a portion of foreign STEM students are likely to return to their country after graduation—for instance, because of the cap on H-1B visas—the US aggregate supply of STEM workers might actually decrease. Despite the lack of growth in the STEM workforce, however, there may be efficiency gains, as displaced students are those comparatively weak in STEM fields and hence are being induced to move to fields in which they are comparatively stronger.

In the face of increasing globalization, understanding the impact of foreign students in college remains an important undertaking. This paper is the first to explore whether foreign students affect college major and career occupational choices. Future research that further explores the mechanisms underlying such effects would be of great value for education administrators and policy makers alike.

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