# Financial Regulation and Automation Adoption: Evidence from Stock Trading Firms*

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**Abstract**

How did trading automation impact broker-dealer firms and workers? While electronic platforms have been available in stock markets for decades, widespread adoption of automated trading occurred only after the major market redesign promoted by the US Securities and Exchange Commission. With the intent of lowering access costs to stock markets, Regulation NMS fostered speed-driven competition in the investment industry. By combining several sources of regulatory records, I construct a rich, linked panel of trading firms and workers with detailed employment records, licenses, and financial information. I show that trading automation increased aggregate profits in the investment industry and induced greater revenue concentration. Consistent with higher technology setup requirements and increased local competition, the entry of new broker-dealers decreases. Survival rates of existing firms display a U-shaped pattern in employment: large, multi-billion dollar investment firms, as well as small brokers who usually engage in proprietary trading, become more likely to stay in business. Trading automation generated significant employment displacement effects, decreasing the probability of stock traders remaining employed, even when compared to investment advisors, bond traders, and other financial workers in less automated markets. Through a series of tests, I show that these results are unlikely to be driven by the Great Recession or the rise in online brokerage services. Overall, my findings offer evidence that trading firms providing services to a small portion of investors benefited from trading automation.

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# 1 Introduction

Electronic trading changed the traditional organization of financial markets. From the 18th century to the late-1990s, equities and derivatives trading took place in exchange-based physical marketplaces, where broker-dealers met to buy and sell financial products for their own accounts or on behalf of customers. As electronic platforms started to proliferate in the early 2000s, machines gradually eliminated much of the need for direct intermediation and floor trading by replacing physical markets with computer networks. Market participants' orders are now routed to electronic systems that fully constitute the trading venue. Matching algorithms organize trade in continuous auctions markets with little human intervention.

The ability to trade electronically at increasing speeds and optimize order handling was soon associated with the rise of new types of market participants. Exchanges created new technologies to extract rents from selling speed advantages and increasingly introduced benefits to reward timely liquidity provision (Budish et al. (2019)). Firms created trading desks specialized in low latency arbitrage and sophisticated algorithms implementing hundreds of parallel strategies, which quickly dominated stock traded volume. The new landscape of stock markets required massive investments in physical infrastructure and human capital.[1] Fairness and efficiency concerns ensued. This technological arms race was seen by many as wasteful and detrimental to the majority of other investors. Michael Lewis' *Flash Boys* famously claimed that automated trading and speed "rigged" the market to benefit "insiders" with deep pockets.[2]

Did technology make trading more unequal? Are profits now more concentrated? Which firms and what type of traders have benefited from algorithmic markets? To answer these questions, I assemble a unique dataset with the universe of US broker-dealer firms and stock traders. With detailed information on traders' employment history, market segment, licenses, firms' performance and IT investment, I investigate the consequences of trading automation for the investment industry. My estimates put a dollar figure on the benefits to automation: on average $98,000 in annual firm net profits for each additional computer per worker. In the aggregate, even relatively modest investments in technology lead to an increase in industry local profits of $1 million.

I begin by constructing a novel dataset combining two sources of broker-dealer data. The first exploits the high degree of regulation on the activity of traders and broker-dealer firms in

[1] When Spread Networks connected Chicago to New York using a straighter fiber cable in 2010, trading firms were eager to pay $16 million upfront to shave 1.5 milliseconds off the time their orders took to reach the exchange's electronic system. Few years later, the technology became too slow (MacKenzie (2021), Shkilko and Sokolov (2020)). Routing times today are as fast as 1 microsecond (0.001 millisecond). Spread Networks intended to raise almost $3 billion in access fees to the cable.

[2] Aquilina et al. (Forthcoming) estimate a cost levied on other traders of $5 billion per year from competition between fast traders.

equities markets. These requirements establish a complex and continuously updated system of licenses and registrations maintained by the Financial Industry Regulation Authority (FINRA) called Central Registration Depository (CRD). To trade professionally or provide financial services, individuals need to take and pass examinations. Because examination applications require an employer's sponsorship, a new license captures not only a worker's new skills but plausible changes in market segment or narrow occupational tasks. I extract all information contained in FINRA's CRD database to construct a longitudinal linked employer-employee panel comprising over 500,000 financial workers — both currently active or that left the industry in the last 30 years — with rich employment history and location, experience, qualification, and market segment licenses. The sample provides a first-time comprehensive portrait of the US stock trading industry at a disaggregated level and without survivorship or selection biases.

The second source of information I leverage uses firm-level financial filings of broker-dealers. The SEC mandates every broker-dealer to submit form X-17A-5 annually. The filing contains detailed balance sheet information, financial income, and leverage. Contrary to commonly used financial filings (e.g., 10-K forms), X-17A-5s are not centrally held in any repository and public versions of the forms are available as scanned paper documents. This requires both search and extraction from each firm's records individually. By linking broker-dealer names from the FINRA database to information from several regulatory systems, I extract over 80,000 unique broker-dealer financial filings spanning 2001 to 2020. I then parse and standardized the contents of each filing into a representative broker-dealer balance sheet and income statement.[3]

To generate variation in the adoption of automated trading by broker-dealers, I use SEC's chief provision to redesign equities trading, Regulation National Market System (Reg NMS). Electronic trading systems for stocks had been available since the 1970s, but adoption by broker-dealers and exchanges was slow. Floor trading remained the leading form of trading even after Instinet's green screen terminals already provided off-exchange electronic trading since the 1980s, and equities markets were long connected electronically by the Intermarket Trading System.

Reg NMS changed this paradigm for stocks by installing price-protection provisions that only apply to stocks in electronic markets and with automated execution, which imposed a minimum speed requirement on participant exchanges. Initially meant to improve stock trading competition between exchanges, price integration steps in the regulation, like Rule 611 in

[3]Recent work by Egan et al. (2019) and Maggio et al. (2019) also compiles some of the data data from FINRA's BrokerCheck, the user interface providing public access to CRD records. Part of the information available in forms X-17A-5 microfounds national aggregate broker-dealer information used in Adrian et al. (2014), which is available from the Federal Reserve Flow of Funds.

the National Best Bid and Offer (NBBO), led to market fragmentation and raised the returns to speed by forcing orders to be executed in the market offering the best outstanding quotes (O'Hara and Ye (2011), O'Hara (2015)).

Because the policy targeted stock markets and not individual firms, mapping changes in market microstructure induced by automation to treated and untreated agents is problematic without knowing each firm's portfolio. The second step I take for identification is to exploit spatial variation in a measure that is likely correlated with local automated trading take-up by broker-dealers. Areas with large pre-existing technology infrastructure in the financial investment industry, measured by computers per worker, face lower implementation costs of more sophisticated technology and imply the availability of basic services to sustain greater automation, such as high-speed internet. This IT intensity allows me to assign heterogeneous degrees of local exposure to electronic trading by comparing worker and firm outcomes in areas with high levels of IT infrastructure to the ones in low-IT areas before and after Reg NMS.

The relevance of the local exposure in broker-dealer firms relates to two channels. First, because of decreased adoption uncertainty induced by Regulation National Market System and if speed is profitable, firms have greater incentive to upgrade technology when barriers to development are lower. Second, if speed is a cost-saving technology and enables firms to cut commission fees, local competition for investors will influence automation take-up. While this second channel largely applies to broker-dealer firms competing for a local pool of customers and the degree of localization in the demand for brokerage services, the first channel is relevant to all broker-dealers trading in stock markets that reward speed.[4]

To validate the intensity measure, I show that areas with higher pre-existing IT exposure have much larger growth rates in patenting related to trading automation, while patents in the finance industry overall and in non-financial sectors behave similarly regardless of this infrastructure. Further, areas with high levels of IT were not accelerating technology investments prior to Reg NMS, suggesting that firms there did not anticipate the increased returns to electronic trading before the policy started to shift exchanges to automated execution.

Centering my first set of analyses on this empirical design, I show that aggregate industry profits in areas with higher automation propensity increased on average by $1 million for each additional computer per worker as a consequence of Reg NMS. This profit growth was fueled by broker-dealers with large book sizes, whose profit participation increases 4 percentage points for the same investment in technology. In fact, interacting the IT measure with firm total assets implies that the same technology investment in JP Morgan and Citadel is $330,000 and

[4]Evidence by Maggio et al. (2019) shows that the demand for brokerage services is extremely local, partially because investors prefer to be close to their brokers. For evidence on the rewards to speed in financial markets, see Baron et al. (2012).

$55,000, respectively, more profitable than in a $100 million asset broker-dealer. Higher returns to technology in larger firms made trading profits more concentrated.

Next, I find that on average firm profits increase by $98,000. To investigate which firms benefit the most from trading automation, I show that existing broker-dealers increase net income on average by $58,000. This implies that new trading firms experience greater benefits from automation. Supporting the conjecture of increase in local competition, firm entry falls by 24 percentage points following the implementation of Reg NMS. The impact on incumbents also reveals important patterns. Small trading firms with less than 50 stock traders and the largest brokers become more likely to survive — with large investment banks being 4 times more likely to stay in business.

These findings underscore the unequal gains from trading automation. While aggregate profits in the industry increased, larger firms became both more profitable and more likely to survive relative to mid-sized brokers. Firms like CJ Lawrence, Susquehanna International, Goldman Sachs, Credit, and Virtu derive most of their trading revenues from proprietary activities and by catering to high net worth investors. My estimates indicating the firm with few traders also become more likely to stay in business aligns with the organizational structure of many of these brokers — small, specialized venues with high investments in IT infrastructure per worker. It is also important to emphasize that some large book-sized brokers, such as Schwab, have invested heavily in increased market access to small and retail investors through online trading resources.

In the next part of the paper, I turn to changes within broker-dealers. Algorithms not only replace repetitive tasks with automated processes, but by large substitute human decision making, operating largely unsupervised for extended periods of time. Trading algorithms make decisions based on pre-established rules that operate by autonomously reading market signals inferred from order flow data. These tools require intensive back-office resources for maintenance and fine-tuning, and take several thousands of person-hours to be developed and tested until becoming operational.[5]

While these new technologies expanded the set of tasks and occupations in broker-dealers and increased the demand for mathematical and programming knowledge, potential labor reinstatement (Acemoglu and Restrepo (2019)) of stock traders did not outweigh displacement. I find that higher exposure to automation decreases the employment probability of stock traders working at the time of the full implementation of Reg NMS by 2 percentage points. I then exploit an additional design to identify employment effects, where I compare stock traders to financial workers employed at broker-dealers working in other market segments. Specifically, I

[5]In *Flash Boys*, Michael Lewis reports that in 2008, Goldman Sachs had over 60 million lines of proprietary trading code.

consider bond traders and investment advisors, whose markets had much lower degrees of automation than stocks. Stock traders become 10-20 percentage points less likely than these other professionals to be employed. When considering all other workers in the investment industry, stockbrokers experience employment losses of similar magnitude.

I supplement the analysis by investigating the role of trading automation in complementing the skills of certain traders who remain employed. Indeed, I find support for electronic trading being a skill-biased technology by comparing wages of individuals in the investment industry in areas with higher exposure to automation. Contrary to the previous analyses, this step pools stock traders with other workers in the trading sector, and includes composition changes by tracking repeated cross-sections of individuals. My estimates show a 9 percentage-point increase in wages of college-educated traders relative to unskilled individuals, translating into \$10,000 annually at the mean for each additional unit of technology investment.

My different empirical designs rest on the identifying assumption that without Regulation NMS, the trend in the outcomes I study would have remained unchanged between treated and control units. Given that Reg NMS became fully operational in October 2007, the potential effects of the Great Recession correlated with treatment intensity are a direct threat to identification. I carefully consider multiple avenues where the financial crisis could impact my results and conduct a series of tests to analyze the importance of alternative explanations.

Particularly, I conduct two main lines of investigation. The first considers that the Great Recession directly drives my estimates through mechanical employment losses and deterioration of broker-dealer balance sheets. Excluding the big 5 investment banks — including Lehman Brothers — has no effects on my results. Alternatively, excluding New York or other large financial centers from my sample only alters marginally the magnitude of the estimates.

Since my specifications allow for worker reallocation between firms after separation, firm idiosyncratic or localized shocks only affect the estimated results if effects of the Great Recession correlate with 2004 IT levels. To test this hypothesis, I use a placebo group of workers unaffected by Reg NMS but that I assume are just as exposed to the Great Recession as stock traders. These comprise individuals employed in all finance areas, including real estate agents, insurance agents, and bankers. The employment effect of this group in higher IT areas is positive, indicating that the the Great Recession is unlikely to drive my results via shocks to the financial sector.

Next, I test for the effects of the financial crisis on the demand for brokerage services. Losses in employment in other sectors could depress household stock holdings and decrease assets under management for brokers. All my results remain unchanged when adding measures of local demand for brokerage services to the baseline model, including local income per capita and stock market wealth following Chodorow-Reich et al. (2021). Further controlling for local home price changes, which absorbs shocks to household balance sheets, also has no impact on my estimates.

Although I cannot rule out the importance of additional channels through which the financial crisis bias the difference-in-differences estimates, taken together these tests suggest that areas with higher exposure to trading automation were not particularly affected by the Great Recession. Finally, I also test the sensitivity of my estimates to the rise in online discount brokerage services. Platforms such as E*trade allowed physical investors the ability to trade using their personal computers and phones. Controlling for local use of online brokerage services also exerts minimal influence on the baseline results.

The rest of the paper proceeds as follows. Section 2 discusses the paper's contribution to the literature. Section 3 introduces the regulatory and technology background in the US trading industry, focusing on the relevant aspects of the policy to my context and its consequences to stock trading. Section 4 describes raw information sources and construction steps of data sets of trading firms and workers. Section 5 shows some patterns of these new data. Section 6 studies which broker-dealer firms benefited from trading automation. Section 7 studies the impacts of automation on stock traders and other groups of workers in trading firms, including quants, clerical occupations, and traders in different market segments. Section 8 assesses the role of the Great Recession and online brokerage services in explaining my results through a battery of tests. Section 9 concludes.

## 2 Relation to Previous Literature

This paper contributes to several strands in the finance and economics literature.

Broadly, my paper complements existing theoretical work showing how new technologies in financial markets shape the investment industry and market participants (Budish et al. (2015), Farboodi et al. (2020), Mihet (2020)). By causally linking trading automation to winners and losers in new financial markets, I show that despite increasing profits in the investment industry, technology investments had several distributional consequences. Trading profits became more concentrated in broker-dealers with larger asset sizes, where technology improvements translate into higher revenues related to smaller firms. These brokers, along with firms employing few traders that specialize in proprietary activities and wealth management experienced increased survival rates, with fewer entrants due to automation.

I also go beyond market microstructure effects (Stoll (2006), Menkveld (2016)) and show how the largest technological change financial markets have ever undergone impacted the investment industry. Several finance papers have looked at how migration to electronic trading affected liquidity provision, quality, and efficiency. Work by Jain (2005), Tse and Zabotina

(2001), Raman et al. (2017), and many others shows that electronic markets increased pricing efficiency and liquidity. Other studies revealed how electronic markets changed market participants (e.g., Raman et al. (2017) for oil markets), which suggests trader composition shifts with unknown consequences to firm and worker outcomes.

My empirical findings further connect a more theoretical-based strand of the literature on the structure of skill and pay in the financial intermediation industry (e.g., Bond and Glode (2014), Reshef and Philippon (2012) and Glode and Lowery (2016)). By providing empirical evidence on employment losses and higher skill wage premia for stockbrokers caused by electronic trading, my analysis underpins skill-biased technologies as a main driver of intensive-margin adjustments in broker-dealers. Trading automation not only substitutes away unskilled work and eliminates repetitive tasks, but also requires high skill work to be operated, impacting the skill composition of traders.[6]

By using the implementation of Reg NMS to flesh out the timing of trading automation in stock markets, this paper naturally stresses the role of financial regulation in directly shaping firm behavior. In particular, it relates to work by O'Hara and Ye (2011) and Haslag and Ringgenberg (2016) who study the effects of Reg NMS and market fragmentation on trading costs and market quality. They find that execution quality and liquidity costs have improved, with the differential in Haslag and Ringgenberg (2016) that only large stocks reaped the benefits of market fragmentation. I contribute to this body of literature by showing how the policy negatively affected trader employment by influencing firms to shift activities towards capital stock.

# 3 Background

I begin by introducing key regulatory changes in the equities trading industry since 2000, in particular Regulation National Market System. I then briefly discuss several dimensions illustrating the dominance of electronic trading in modern financial markets. This discussion sets the stage to highlight the sharp changes to the structure of stock trading beginning in 2005.

## 3.1 Financial Regulation: Institutional Framework

Since the creation of the National Market System (NMS) by the Securities Acts Amendments of 1975, US securities markets have been partially integrated in an attempt by policy makers

[6] This is also related to a large strand in the literature investigating the impacts of technological change on labor markets (e.g., Autor et al. (2003), Acemoglu and Restrepo (2019), Acemoglu and Restrepo (2020), Acemoglu and Autor (2011), Aghion et al. (2020)).

to provide greater transparency and foster competition between trading venues. The NMS created a central marketplace where quotes once scattered across different exchanges could be publicly displayed. In the 2000s, the SEC introduced new regulation as a response to the development of new market mechanisms and electronic stock exchanges which rendered the 1975 national market system outdated.

**Regulation ATS.** Implemented in 2000, SEC Regulation ATS extended the reach of existing rules to include automated trading systems (ATS) under the national market system. Automated trading systems are one type of algorithmic trading and use sophisticated computer programs to generate and execute buy and sell orders. Reg ATS offered ATSs the option to register as an exchange or a broker-dealer, which initiated the integration of these automated off-exchange systems with traditional financial centers.

**Regulation NMS.** Following Reg ATS, Reg NMS was passed in 2005 and became fully effective in October 2007, after major exchanges requested additional time to adapt to the policy provisions. The set of rules intended to promote "*efficient and innovative trading services*" and "*more efficient pricing*" of stocks by fostering "*vigorous competition among markets*", in addition to "*integrated competition among orders*".[7] The dramatic redesign of the national market system centered in a new requirement for brokers to execute customer orders at the best available quote (top-of-book). The most important and contentious provision of Reg NMS, the Order Protection Rule (Rule 611), known as "trade through" rule, mandates intermediaries to direct orders to the venue posting the best available quote, which is protected from trading through (executing the order at a suboptimal price).

Only automated quotes — offering immediate display in the NMS, now consolidated under the NBBO (National Best Bid/Offer) — were subject to the Reg NMS price protection. Receiving this benefit was seen by exchanges as essential to attract order flow (Spatt (2018)), which along with other provisions in the regulation profoundly changed stock trading and the investment industry in the US.

Reg NMS is widely acknowledged as one of the main causes of market fragmentation and the rise of speed-driven competition in US financial markets. First, because Reg NMS only protects electronic quotes, stock exchanges had an incentive to adopt electronic limit order books (Chao et al. (2018)), boosting execution speed as automated order entry and execution is inherently faster than manual quoting. Hendershott and Moulton (2011) argue that NYSE introduced its Hybrid Market (which expanded trading automation and consequently reduced latency) to meet the criteria of Rule NMS. Pagnotta and Philippon (2018) show that order execution speed in the exchange decreased over 10-fold within weeks following automation.

[7] Text of SEC's Regulation NMS. More details in `https://www.sec.gov/rules/final/34-51808.pdf`.

Second, since Rule 611 routes trading volume to venues offering lower quotes, it mechanically increases off-exchange volume and thereby fragmentation. Off-exchange ATSs, such as electronic communication networks (ECNs) and dark pools, now account for 44 of 57 US trading venues and much larger market shares. By 2013, dark pools had a two-fold increase in market share from 7% in 2008 (Kwan et al. (2015)). Traditional exchanges saw sharp drops in market share: equity market volume held by NYSE and NASDAQ decreased from 70% and 50% in 2006, respectively, to 20% and 30% in 2011 (Pagnotta and Philippon (2018)).

Under market fragmentation, quotes are scattered across a larger number of markets and search costs increase. Biais et al. (2015) sets up a model in which fragmentation cost reduction induces investment firms to overinvest in speed-driven technology. Competition between exchanges also lead to significant increases in trading speed. In order to attract volume and reduce execution latency, exchanges cut transaction fees (Colliard and Foucault (2012)) and invested in new infrastructure to make trading faster (Pagnotta and Philippon (2018)). But these new capabilities could only be explored by trading firms undertaking significant investments in IT hardware and automation software.

Overall, Reg NMS fostered speed-driven competition in two ways. By imposing a minimum speed requirement (electronic trading and automated order entry), the legislation rendered the existence of purely floor-based exchanges economically unattractive. Second, price integration policies, like Rule 611, result in market fragmentation (Pagnotta and Philippon (2018)), which make latency a central market structure issue. US exchanges are for-profit companies that generate revenue out of fees accruing from trading volume. If trade volume is directed to cheaper venues, exchanges lose market share and trading revenue. Taken together, these two facts increased the returns to trading speed and lowered adoption uncertainty, likely contributing to the rise of algorithmic trading, in particular of high-frequency traders (HFTs).[8]

## 3.2 The Slow Rise of Electronic Trading

Electronic financial markets are not particularly a recent innovation. Launched in 1969, Instinet was the first and only electronic communications network in Wall Street, competing with traditional floor-based exchanges. Only after the diffusion of PCs in the 1980s, non-physical trading started to fully develop, in part because of regulation following the crash of 1987 pushing exchanges to adopt automated execution systems.

Transitioning to electronic markets, however, was a slow process. Traditional exchanges operated under secular systems of memberships, where trading advantages come from mem-

[8]With time, exchanges developed new ways to exploit electronic trading and the presence of algorithmic traders to increase profit beyond volume-based trading fees, including offering co-location slots to reduce speed latency, and several complex fee schema based on quoting activity.

ber benefits — liquidity externalities attracted volume which begat volume. Floor-brokers pushed back automation, fearing both skill obsolescence and loss of trading fee revenues, as most exchanges were then non-profit organizations owned by physical traders. As late as 2003, NYSE's chairman Richard Grasso vigorously defended open outcry trading. Following Grasso's ousting, Chief Executive John Thain pushed the exchange to further develop electronic-based trading systems. NYSE merged with Chicago's Archipelago Exchange in 2005, then, a leading ECN, following Nasdaq's purchase of Instinet. NYSE's merge (which also resulted in the company going public and becoming for-profit) was part of the hybrid market initiative. The move still faced opposition of several floor brokers — self-named "Independent Broker Action Committee" — who claimed that automation would "*leave floor brokers out of major trades, limiting their access to liquidity and threatening their livelihoods*". Thain responded that "*while a small number of people, although vocal, are opposing*" automation, "*the vast majority of brokers are very supportive*". He also referred to floor specialists as a "bottleneck", eroding the exchange's market share and slowing down trading.

The late adoption of electronic platforms by major exchanges (NYSE's initial steps in 2001 and 2004, NYMEX in 2006, and ICE in 2008) shows the uncertainty and challenges surrounding the adoption of electronic markets. A notorious example of skepticism with respect to electronic trading adoption in the late 1990s not exclusive to stock markets is the case of the former futures exchange CBOT. In 1997, the legendary exchange took a gamble against its rising competitor — CME's electronic platform Globex, introduced in 1992 — by building a $300 million, 65,000 ft. trading floor in Chicago. Called the "Taj Mahal", the new physical floor represented the belief of many in the investment industry that physical trading offered advantages to automation and would out-compete electronic marketplaces. In December 1998, chairman Patrick Arbor was voted out of office by CBOT members because of his attempt to offer the exchange's derivatives contracts at Eurex's electronic platform. Ultimately, CBOT was purchased by CME in 2007. Open outcry trading in the exchange's floor shut down in 2015, following the trend from competing venues, like ICE, who went all-electronic in 2012.

## 3.3 The Fast Dominance of Algorithmic Trading and Its Consequences

The previous discussion provided background on the importance of Reg NMS in fostering speed-based competition and lowering development costs of algorithms and of the structure necessary to fast trading. Because the policy raised the returns to automated execution, it is likely to have influenced the timing and intensity of electronic trading adoption by broker-dealers and exchanges.

After Reg NMS came into effect, trading automation sharply dominated US stock markets. I illustrate the speed and impact of this movement in two ways. First, Figure 1 shows real-side patterns of the technology arms race in stock trading firms in the last decade. It plots investment in IT capital stock by broker-dealers over time — these include computers, mainframes, storage capacity, data technologies, as well as expenditures on software development and adoption. The data show a three-fold increase in IT investments from 2005 to 2010, when it reached $30 billion a year. The trend was accompanied by a fast decline in stock trading employment, which added 40,000 jobs in 2000-2007 and eliminated 60,000 since then. Employment levels in 2015 were similar to the 1990s, when the financial sector represented a much smaller share of the US economy (Philippon (2015)).[9]

This accelerated investment in IT capital had profound effects on stock markets. Figure 2 compares the daily number of traded stocks in the US by market participant segment. High-frequency trading alone — the most sophisticated form of automation — accounted for over 60% of US daily equity volume in 2009 compared to 20% in 2005, according to data from the Tabb Group and Credit Suisse displayed in the figure's first panel. The pace of volume growth is even more striking when contrasted with the evolution in active and passive money managers and investors between 1999 and 2009. Without HFT presence, total traded volume in US stocks grew from just below 1 billion shares a day to 4 billion over the entire decade. In six years, volume traded by high-frequency traders increased from virtually zero to over 6 billion daily shares. The second part of Figure 2 plots floor broker employment at NYSE, which precipitously fell after the exchange introduced its hybrid system.

# 4 Broker-Dealer Firms and Workers

## 4.1 US Broker-Dealers

Workers and firms in the US securities investment industry are required to be registered and obtain activity licenses from the Financial Industry Regulation Authority (FINRA). The self-regulatory agency oversees broker-dealer operations and conduct, organizes and applies examinations that enable individuals to work in certain market segments or job titles. A firm initiating sales activities in equities markets must file Form BD (Uniform Application for Broker-Dealer Registration). Employee registration records are kept through routine updates to Form U4 (Uniform Application for Securities Industry Registration or Transfer), which must

[9]These are primarily the type of workers represented in the UBS trading floor picture circa 2005 in Figure A.1. These traders would send orders and communicate with floor brokers, for example, at NYSE's trading floor, whose employment time series I show in Figure 2.

be amended within 30 days of material changes (e.g., new employment, license, disciplinary action).

These records are publicly available and contain rich information on worker and firm-level data spanning decades. FINRA maintains the Central Registration Depository (CRD) which includes all securities brokers, traders, and firms currently active or that were ever registered to operate. The database also includes workers not necessarily executing stock trades or selling equities investment products, such as investment advisers, commodities traders, and several other trading professionals that also require licensing. In sum, if an individual deals with investment-related activities and has a broker-dealer as an employer, her records are available at CRD.

FINRA grants access to CRD through the search website BrokerCheck.com. The platform allows the public to retrieve records on a specific broker-dealer or trader by searching their name, registration code, or location. One example of the platform output is shown in Figure (A.2).[10] To assemble the dataset, I scrape all broker-dealer records in FINRA's CRD and homogenize each individual's record into a comprehensive sample containing over 1.2 million individuals currently active, inactive (no longer registered), and who left the industry in the 1990s. The latter group is discarded as broker-dealers employed only prior to 1990 have incomplete records.[11]

For each worker, I observe complete employment history by employer's name, litigation history, years of experience, licenses, and full name. With workers' employment records, I construct a broker-dealer longitudinal panel tracking firm location and workforce by financial occupation or job title. There are about 10,000 unique broker-dealer firms registered in the database over 1990-2019 and over 5,000 continuously operating from 2001 to 2015, which I use as my estimating period.

I complement the detailed trader information from FINRA with data from the Current Population Survey (CPS) and 3% samples of Census American Community Survey (ACS), which are less prone to sampling error than annual 1% waves and provide information on trader wages and skills, and allow me to investigate how unlicensed professionals working at broker-dealers (e.g., software engineers, data scientists) responded to trading automation adoption. Only workers of ages 18 to 64 and earning work wage are considered. Census Public

[10] Although these data are freely accessible online and are intended to offer greater transparency for regulators and customers who wish to consult professional records, the database remains largely unexplored. In finance, Egan et al. (2019) and Maggio et al. (2019) use some of FINRA's BrokerCheck records to study financial adviser misconduct and institutional investor demand for brokerage services.

[11] For example, details on employment history for these traders are limited, or just the last employment firm is recorded. For all individuals active after 1999, FINRA requires any changes to employment, registration, or licenses, to be reported and updated in the system within 30 days.

Use Microdata Area (PUMA) geographies are mapped onto counties by allocating the share of population in each PUMA to a county.

## 4.2 Financial Filings

As mandated by Section 17 of the Securities Exchange Act of 1934, Rule 17a-10(a)(1), registered broker-dealers are required to submit form X-17A-5, also known as FOCUS (Financial and Operational Combined Uniform Single) Report, every fiscal year. The form is mandatory even for privately-held broker dealers and generally contains a statement of financial condition (balance sheet), financial income and operation, as well as calculation of the Uniform Net Capital Rule (Rule 15c3-1). Although some information is not publicly available, such as detailed holdings position, publicly available records always contain broker-dealer balance sheet, leverage computation, and often statement of income, as well as market value of investments, wage bill, and capital or operational expenditures in technology.

Contrary to other financial data readily available to the public, including from forms 10-K and 8-K, until 2017, X-17A-5 documents were submitted only in paper and not indexed in SEC's Index Files. This makes scraping and handling these forms a much more difficult task than parsing financial information from most other filings. The SEC publicly stores only PDF scans of paper filings along all other documents filed by a certain entity.

To retrieve and process financial filings from US broker-dealers, I employ a lengthy process described in detail in the Appendix. The approach first exploits broker-dealer names obtained from the FINRA records, which are then matched to SEC's Central Index Key (CIK) codes. Next, I screen under which entity names or filing codes a broker-dealer files its relevant documents, retrieving each filing's Document Control Number (DCN) path. This final step allows me to access and download each filing.

Finally, after obtaining over 80,000 annual X-17A-5 forms in PDF or image format spanning 2001-2020, I convert these files into readable text and extract financial information by homogenizing different reporting standard across the firms. The resulting sample and information available for balance sheet and statement of income are displayed in Figure A.6.

## 4.3 Information Technology

I obtain firm-level IT data from the marketing company Aberdeen. The CI Technology Database (formerly offered by Harte Hanks) contains detailed information on the hardware and software used in over 400,000 business sites in the US. For each company in 2004, one observes granular location, employment (overall and desk workers), industry code, company name, revenue, number of programmers, storage capacity, mainframe machines, PCs, internet access type, and IT variables along several other dimensions. Similar to Bloom et al. (2012) and Beaudry and Lewis (2014), I construct firm $j$'s IT intensity measure as the number of computers per desk worker, $IT_j^{fin}$.

Using only firms with NAICS industry codes 523 (Securities, Commodity Contracts, and Other Financial Investments and Related Activities) and 525 (Funds, Trusts, and Other Financial Vehicles), indexed as $fin$, I calculate local historical IT intensity as

$$\overline{IT_c^{2004}} \equiv \frac{\sum_{j \in j(c)} \omega_j^{fin} IT_j^{fin}}{\sum_{j \in j(c)} \omega_j^{fin}}$$

where $\omega_j^{fin}$ is total employment at firm $j$ and $j\,(c)$ are $fin$ companies in county $c$. More details on patterns of the IT intensity measure are provided in the next section. Figure (A.3) shows that the IT intensity in the investment industry was already relatively high compared to other sectors, with an average of about one computer per worker.

## 4.4 Other Data

To lend further credibility to the main pre-policy IT measure, I construct a second pre-Reg NMS intensity measure based on local broadband availability. The data come from the Federal Communications Commission (FCC), which provides internet access information from Forms 477. The data is available for most US ZIP codes, and tracks the number of high-speed (200 kilobits per second or faster) internet providers with at least one subscriber per ZIP code. Access to high-speed internet is a minimum infrastructure requirement for firms trading electronically, especially those with with high-frequency database and back-end services, such as co-location and access to price feeds from exchanges.

I map 5-digit ZIP codes onto 2010 census counties by assigning the latitude and longitude of the ZIP code centroid to a unique county. In each county, I aggregate the number of different high-speed internet providers into an alternative intensity measure $\widetilde{IT_c^{2004}} = \frac{\sum_{z \in z(c)} \psi_z providers_z}{\sum_{z \in z(c)} \psi_z}$, where $z\,(c)$ gives the set of ZIP codes contained in county $c$ and $\psi_z$ are allocation factors based on the fraction of the county area occupied by each ZIP code.

In certain specifications, I control for potential factors affecting the demand for brokerage services. Personal income per capita data comes from the US Bureau of Economic Analysis (BEA) and dividends and labor income from IRS Statistics of Income data. To construct local stock market wealth, I follow the same methodology in Chodorow-Reich et al. (2021). Specifically, I retrieve Form 1040 aggregate dividend amount in a county $c$ and income from wages and earnings to construct local stock wealth as

$$\eta_{ct} = \left( \frac{D_{ct}}{w_{ct} L_{ct}} \right) P_t^{\text{S\&P 500}}$$

where $P_t^{\text{S\&P 500}}$ is the inverse of the dividend yield (price/dividend ratio) on the S&P 500.

# 5 Anatomy of the US Trading Industry

This section presents both suggestive evidence of the effects of Regulation NMS and details of the US broker-dealer data. I start with descriptive facts in the data.

Table 1 presents descriptive statistics for the top 10 counties of stock trader employment in 2004 and 2009. As expected, New York accounts for the majority of equities trading jobs in the US, with about a quarter of total employment before Reg NMS and 20% as of 2009. Other important financial centers like Chicago and Los Angeles tend to concentrate fewer broker-dealer jobs than areas in New Jersey, which has a large number of trading firms, data centers, and overall investment industry infrastructure. The pre-policy IT intensity considerably varies across counties. Boston and New York ranked considerably higher than other top employing areas in use of PCs per worker. Since a disproportionate number of trading firms and broker-dealer individuals in the sample are in New York, later in the paper I test for the sensitivity of my main estimates to excluding the city from the analysis, as well as other top financial centers.[12]

Table 2 shows similar employment trends but now focusing on top broker-dealer employers. These are large investment banks, such as Morgan Stanley, JP Morgan, Merrill Lynch, and RBC Capital Markets, as well as large asset managers like Schwab, Fidelity, and Edward Jones. While the vast majority of these employers considerably decreased stock trader employment between 2004 and 2015, some firms, like JP Morgan, added about 1,000 traders. However, when compared to the expansion in total personnel, the ratio of stock traders to workers decreased from 64% to 19% — a similar trend in all other brokers. Other investment workers include any employee directly involved in the process of sales, research, management, or in advisory capacity of equities products and investment services. These do not include, necessarily, computer technicians, software developers or programmers, contract lawyers, and office personnel, unless these individuals were ever involved in the activities mentioned.

Taken together, several pieces of descriptive evidence indicate large declines in stock trader employment, even as workers in other market segments or occupations within broker-

[12] For a spatial visualization of the evolution in stock trader employment, see (Figure A.7).

dealers did not necessarily experience the same trends. Figure 3 takes a closer look at entry and exit of various investment worker groups to shed light on the relative contribution of the two margins driving these aggregate patterns.

During the 2003-2007 period, increasing numbers of individuals became stock traders, a similar trend followed by investment advisors. After 2007, the entry of both groups gradually declined until becoming stable at relatively low levels. Entry in municipal bond trading is much less pronounced, trending slightly upward in the last 20 years. Commodity traders saw larger employment entry until 2012, also slowing down after that. The second panel of the figure shows annual counts of workers exiting the investment industry according to their last occupation recorded. These are net of separation effects and occupational or market segment switching withing and between broker-dealer firms.

Starting in 2005, stock traders quit the industry at an increasing pace. In 2008, over 20,000 traders left broker-dealers, remaining around 15,000 a year since then, more than three times the rate of the early 2000s. Other market segments also experienced large numbers of departure.

Figure 4 plots data compiled from forms X-17A-5 compiled from 2002 to 2015. These are the top 30 broker-dealer firms in the period in total asset size. Not surprisingly, large investment banks including JP Morgan, Morgan Stanley, Credit, BNP Paribas, and UBS have massive balance sheets — all above $100 billion on average. Indeed, balance sheet size is extremely concentrated in the US trading industry. Across over 4,500 broker-dealers, these 30 firms alone account for over 50% of the $4 trillion in total assets in the sector.

Figure 5 shows average net income of selected firms at the top and end of the performance distribution. Earnings distribution in the cross-section and time-series is very volatile. In the short cross-section illustrated, Edward Jones made on average $200 million in net profits while MacQuare Capital lost $100 million. In the time series, performance (and financial assets) may oscillate anywhere from hundreds of millions to several billion dollars year-over-year. Since by far the most important determinant of broker-dealer performance is some version of financial result from trading profits, it is not surprising that balance sheet in the industry presents so much variation.

# 6 Profits, Concentration, and Firm Performance

## 6.1 Empirical Strategy

I quantify the causal effects of trading automation on broker-dealers using a difference-in-differences with continuous treatment design (Card (1992)). Reg NMS fostered speed-driven competition by imposing a minimum trading speed requirement on stock exchanges and increasing the returns to fast trading. Exploiting spatial variation in local IT intensity in the finance industry, my main goal is to instrument for technology take-up, which is endogenous to firms, according to the following logic. Because technology upgrading and migration to electronic trading is facilitated by pre-existing infrastructure, I expect markets with higher IT capital stock in financial firms to be more affected by the policy.

**Baseline model.** In my baseline specification, I run the following model for broker-dealer firms:

$$y_{fct} = \alpha_0 + \delta \left( IT_c^{2004} \times \text{Post RegNMS}_t \right) + \gamma X_{fct} + \lambda_t + \mu_c + \varepsilon_{fct} \qquad (1)$$

where several outcomes at the firm-level $f$ located in county $c$ in year $t$ are regressed on: the pre-policy IT exposure variable, $IT_c^{2004}$, which is interacted with an indicator for the post-Reg NMS period, Post $\text{RegNMS}_t \equiv \mathbb{1}\{t \geq 2007\}$. To assess aggregate trends, in some regressions I use county-level outcomes, i.e., $\sum_{f \in c} y_{fct}$.

I include time-varying controls in $X_{fct}$ that could be omitted variables otherwise left out of the model, such as local income per capita and local stock market wealth. Year fixed effects $\lambda_t$ capture aggregate shocks affecting all counties with the same incidence, e.g., S&P 500 returns and the business cycle. To the extent that stock market fluctuations could exert differential effects in areas with higher investor density, the covariate for stock market wealth captures not only local consumption wealth effects as in Chodorow-Reich et al. (2021), but also the possibility that households may reduce risky asset holdings to smooth negative labor income shocks. County-fixed effects $\mu_c$ are further included to control for unobserved determinants of employment for each county, also absorbing the level of pre-policy IT use.

**Identifying assumption.** In model (1), the key identifying assumption is that without Regulation NMS, the trend in the outcome would have remained unchanged independent of the IT intensity.

## 6.2 Validating IT Exposure: Evidence from Trading Patents

The IT exposure measure I construct intends to capture the existing level of local infrastructure in the finance industry. The relevance from assigning treatment with the measure relies on the assumption that trading automation take-up correlates with this infrastructure. One useful way to test for this assumption is to consider whether electronic trading and automation services also increase in line with local exposure.

Many trading algorithms and back-end systems are developed by specialized companies who sell these products and services to broker-dealers. This end-consumer market provides incentives for developers of trading engines and systems to file for patents to protect intellectual rights. Areas with large generation of electronic trading-related patents are likely to have a thicker market for automated trading tools, as close location to electronic network development firms is important for broker-dealers. Computer systems in trading firms undergo maintenance often. Proximity also facilitates fine-tuning and customization of automated trading strategies and off-the-shelf agency algorithms, which can be easily adapted to a firm's particular needs.[13]

To determine patents related to trading automation, I search through all patent description records from 1976 through 2018 in the United States Patent and Trademark Office (USPTO) database, and select those related to electronic trading based on a combination of terms inventors used to link the patent use to electronic markets. I retrieve the year the patent was granted, the name and geocoordinate of the company listed as "assignee", the investor's name and home address. To benchmark the measure against other patents, I also construct local measures of patents related to any financial industry, and all non-finance patents. Appendix (9) gives further detail on the retrieval process.

To illustrate what technology type is represented by trading automation patents, consider the example of patent US7844541B2, issued in 2009 to the Chicago firm Trading Technologies International, Inc. The patent describes a "*system and method for quick quote configuration*", allowing traders "*to quickly configure the quoting side of a trading tool, without experiencing the normal delays associated with conventional methods of quoting*" by "*automatically work*[ing] *an order to buy or sell a tradable object*". The firm provides trading tools, data flow, and other services to support electronic platforms.

The first panel in Figure 7 shows growth rates in local patents for the trading automation, finance, and non-finance measures. Patents are aggregated from address to the county level. Trading automation patenting experienced an accelerated increase following Reg NMS. The growth rate was over 2-fold that of the overall finance industry and several orders of magnitude faster than non-finance patents, which in the counties with broker-dealers remained relatively stable over 1980-2010. The second panel in the figure decomposes the trading automation patent measure according to the IT exposure of their area. Areas with more pre-existing IT infrastructure account for almost the entire growth in trading automation patents.

These aggregate patterns are suggestive, but do not link the growth in the availability of automated trading technology to Reg NMS and IT exposure. To formally establish this link, I regress

$$\ln\left(\text{Patents}_{ct}^{g}\right) = \alpha_0 + \pi\left(IT_c^{2004} \times \text{Post RegNMS}_t\right) + \theta_t + \omega_c + u_{ct} \tag{2}$$

[13] I use the year the patent is eventually granted and not when its application started to capture the market availability of the technology (supply-side) rather than the innovation timing. It is important to acknowledge that patents in this context do not incorporate proprietary algorithms developed within broker-dealers, which are well-kept trade secrets. Accused of stealing proprietary trading code from Goldman Sachs, former employee Sergey Aleynikov was prosecuted for years.

where the outcome measures the aggregate number of patents in group $g = \{\text{trading automation, finance, non-finance}\}$ from inventors living in county $c$.

Table 3 compares the difference-in-differences estimates across each patent group. While trading automation patenting increases by 14.7% with each additional computer per worker, there is no relationship between areas with more availability of these patents and patents in overall finance or non-finance sector.

### 6.3 Industry Profitability and Firm Performance

Table 4 begins by investigating how trading automation affected industry profits. Column (1) calculates county-level aggregate net income of all broker-dealers with complete records. The measure allows for both entry and exit of firms, and only discards brokers without eventual records despite being active — either because the SEC did not make the operating income part of form X-17A-5 public or the paper document copy was unreadable by OCR. The difference-in-differences estimate shows that for each additional computer per worker, local aggregate broker-dealer profits increased by $1,009,000 a year. This is a crucial result: electronic markets made the industry in areas more likely to automate more profitable.

Column (2) considers all broker-dealers with available net income information before calculating county aggregates. The intuition here is that if missing values in column (1) are systematically associated with more or less profitable firms, the estimated effect may incorporate measurement error. When incorporating firms that do not have net income information despite having filed their forms, the estimated increase in aggregate profits is 40% larger, suggesting that the first estimate is, if anything, understating the profit growth.

The next result looks at whether larger profits were distributed equally to all firms. In column (3), I calculate the share of local profits at the above-median largest broker-dealers (defined by total assets, which for broker-dealers largely represent financial assets). The estimated effect shows an important distributional consequence of automation. By increasing one computer per worker in a local area, largest brokers increase their profit share by 4 percentage points. Taken together, the two effects show that the trading automation boosted investment profits, but larger firms benefited more than small broker-dealers.

**Broker-dealer profit.** The next set of results turns to firm-level net income to compare how firm profitability responded to automation. Column (1) of Table 5 indicates that one additional computer per worker increases firm net income by $98,000. This specification pools firms within the same county before and after Reg NMS, incorporating both composition changes and firms potentially not directly affected by the regulation's introduction. Adding year dummies has little impact on the estimate. In order to understand whether the increase in industry profits stems from entry of more profitable firms, or whether automation fostered the profitability of the incumbent firms, I estimate a specification with broker-dealer fixed effects. The estimate in Column (3) indicates that incumbent firms benefited from automation, however, the coefficient is smaller in magnitude by half, increasing existing firms' profits by $53,000. This is estimated off brokers reporting net income at least once before and after 2007, therefore more cleanly estimating the intensive margin response to the policy. Comparing the two estimates reveals that, while incumbent firms became more profitable, a large source of increase in the industry profitability came from more efficient entrants or less profitable firms being driven out of business. Columns (5) through (8) replicate the previous estimates interacting the policy term, $IT_c^{2004} \times \text{Post RegNMS}_t$, with firm's total assets. The triple interaction shows that larger brokers, increased profits even more relative to others in more exposed areas.

### 6.4 Survival and Entry

Next, I analyze how the policy affected industry composition, namely, how it affected broker-dealer survival and entry rates. Table 6 begins by analyzing how likely, on average, broker-dealer firms were to stay in business in the next 5-years. Across all firms and counties, brokers in high IT areas were about 2 percentage points more likely to survive. Decomposing this pooled coefficient according to firm size reveals several patterns. First, both the smallest and largest firms account for the higher average survival rates following automation. Employers with more than 1,000 traders were as much as 8 percentage points more likely to stay operating. Second, mid-sized firms with contingents of stock traders in line with local branches and small-operated targeting primarily financial advising were just as likely to survive regardless of automation.

## 7 Impact on Traders

This section focuses on the impact of trading automation and new technologies in the investment industry on financial workers. I combine my baseline empirical design, which exploits local variation in IT intensity to instrument for automation adoption following Reg NMS, with a standard binary difference-in-differences approach comparing stock traders to investment workers plausibly unaffected by trading automation.

## 7.1 Employment

I first modify the baseline model (7.1) by running worker-level regressions of the type:

$$\Pr(Employed = 1)_{ict} = \alpha_0 + \delta \left( IT_c^{2004} \times \text{Post RegNMS}_t \right) + \gamma X_{ict} + \lambda_t + \mu_c + \varepsilon_{ict}$$

where all variables are as previously defined, except for the outcome which is now a dummy equal to one if worker $i$ is employed in year $t$. The specification above leverages the granularity of FINRA's CRD records, which enables me to construct a detailed employment path stemming from a technology shock in the following manner. I consider all stock traders employed in 2007 in county $c$ and track their employment status over time at any firm $f$ or location. I then consider a stock trader as leaving the occupation (or "unemployed" as a stock trader) if the individual i) obtains a new license to work in a different occupation or market segment at $t^*$, for which I assign $\{\text{Employed}_{ict}\}_{t \geq t^*} = 0$, or if she ii) is currently not employed by any broker-dealer in $t^{**}$, $\text{Employed}_{ict=t^{**}} = 0$.

The first condition imposes that when switching roles or market segments, the trader leaves permanently, regardless of her actual employment status. The second allows for re-entry in any year in case the stock trader becomes employed again. Overall, this approach allows for both firm and location reshuffling, only pinpointing workers to their local of work to be treated by $IT_c^{2004} \times \text{Post RegNMS}_t$. Finally, this procedure also defines the estimating sample.

The specification above directly tests for the impact of trading automation on stock trading employment. My second, complementary approach compares outcomes of these workers to other investment professionals plausibly unaffected by Reg NMS. I focus on market segments and jobs within broker-dealers less exposed to electronic trading or task automation. Specifically, I compare stock traders to investment advisors and municipal bond traders, two markets with low penetration of automation by electronic systems, and to all non-stock traders combined to avoid potential selection bias.

Financial or investment advising (IA) is closely related to the role of stock trading — in fact, many traders also hold IA licenses. Pure investment advisors focus solely on client-relationships, most commonly acting as sophisticated financial planners. They provide asset allocation recommendations to clients, usually using or conducting research analysis on equities products, including stocks. More recently, the emergence of robo-advisors — particularly popular among millennial investors — which offer low-cost ETFs, automatic portfolio rebalancing, and investment analysis, has also exposed IAs to technological displacement. However, robo-advisors were only introduced in 2008, and assets managed through these services were virtually zero until 2014, according to data from the Aite Group. To construct the investment advisor control group, I consider individuals holding an IA license (granted by passing the Series 65 exam, known as "*Uniform Investment Adviser Law Exam*") who never hold a joint stock trading license.

The second group I consider are municipal bond traders, who must obtain a license from Series 50 through 54. Municipal bond trading occurs in a much different environment than stock trading. Markets are opaque, decentralized, and largely voice-based, with low penetration of electronic trading relative to stocks or derivatives. Focusing on IAs and muni bond traders also has a practical reason: these are among the best well-defined groups in FINRA's examination and license system that allow me to exclude tasks related to stock trading. To provide as broad as possible comparison group, the third control set of workers I consider excludes all individuals ever holding a stock trading license and pools all workers in the investment industry.

If trading automation is a labor-saving technology, particularly in cognitive and manual tasks that can be subsumed by automatic rules (Autor et al. (2003)), one expects low-skill employment to respond negatively to greater adoption of electronic trading. The magnitude of this extensive-margin adjustment depends on the skill composition of affected workers and whether electronic trading is a skill-biased technology. For example, if algorithms and greater execution speed make the traders able to use these tools more productive, low-skill traders are more likely to be fired and wages of highly-skilled workers will increase. In the previous sections, I showed that the volume of stocks traded in the US — a rough output measure — increased dramatically since 2005. This growth was almost entirely attributed to automated orders.

**Baseline model.** Baseline results are displayed in Figure 8. I begin by investigating the presence of pre-trends in stock trader employment at various different levels of IT intensity. In light of the identifying assumption for the baseline specification, the presence of parallel pre-trends across different intensity values provides credibility for the design. The figure shows that traders employed in 2007 had similar trends of employment in areas with different degrees of pre-existing IT infrastructure. The second panel in the figure plots dynamic estimates of the baseline model,

$$\Pr(Employed = 1)_{ict} = \alpha_0 + \sum_{k=2001}^{2015} \delta_k \left( IT_c^{2004} \times \mathbb{1}\left\{k = t\right\} \right) + \gamma X_{ict} + \lambda_t + \mu_c + \varepsilon_{ict},$$

which interacts $IT_c^{2004}$ with a full set of year dummies. To plausibly attribute any effects on employment to the introduction of Reg NMS, the IT intensity measure should correlate with post-policy trends in the outcome, but not prior to 2007: we expect $\widehat{\delta_k}$ for $k < 2007$ to be non-significant.

Results show that stock traders experienced large declines in the probability of remaining in the occupation as a result from automation adoption. Just shortly after Reg NMS is fully implemented, stock traders are 2% less likely to be employed for each additional PC per worker. To put this magnitude in perspective, consider that based on the raw employment probability in the figure's first panel, traders working in 2007 were almost as likely to be working back to 2001. In other words, immediately following Reg NMS, stock trader employment declines by more than the accumulated pre-level of separation.

**Control workers.** Figure 9 plots coefficients of a similar dynamic difference-in-differences model, now exploiting groups of workers employed by broker-dealers as control individuals to stock traders. Across investment advisors, municipal bond traders, and all other non-stock traders, employment of stockbrokers declined between 10 and 20 percentage points following Reg NMS. Pre-2007 estimates show no statistical difference between employment of these groups and stock traders, confirming the role of the policy in structurally changing the nature of stock markets to traders. Note that these regressions compare workers in the same county, similar to the IT intensity design. Overall, results remain unchanged when controlling for the demand of local stock brokerage services, or including broker-dealer fixed effects.

## 7.2 Other Broker-Dealer Workers

As broker-dealers replace stock traders with electronic systems and automated execution, do they increasingly employ other professionals? To analyze the extensive labor response of trading automation adoption, I turn to other occupational groups employed in the investment industry. Using county-level employment of five groups of workers, I run the following regressions

$$\ln\left(Employment\right)^{o}_{ct} = \alpha_0 + \delta\left(IT^{2004}_{c} \times \text{Post RegNMS}_t\right) + \gamma X_{ct} + \lambda_t + \mu_c + \varepsilon_{fct}$$

which use log employment levels of five worker groups $o$, Quants, Financial Analysts, Investment Advisors, Tax and Audit, and Brokerage Clerks.

The first group, Quants, includes computer scientists, programmers, developers, computer hardware and software engineers, and IT support specialists. With higher investment in IT infrastructure and the need for development, maintenance, and support, broker dealers may increase the demand for within-firm presence of these professionals. The second group, Financial Analysts, also usually involves highly-educated individuals considered "quants", but whose skills are employed in financial research, modelling, and risk and portfolio analysis. New data technologies in the investment industry likely expand the role of these professionals. Investment advisors represents the same occupational group that I observe with precision and granularity from FINRA's records, and we should expect null employment effects. I include this group as a check for using Census employment data in the investment industry, similar to tax and audit professionals.

The final group, Brokerage Clerks, provides an important related occupation to stock trading. The US Bureau of Labor Statistics describes brokerage clerks as performing duties including "*writing orders for stock purchases or sales, computing transfer taxes, verifying stock transactions, accepting and delivering securities, tracking stock price fluctuations, and keeping records of daily transactions and holdings*". The need for these routine manual tasks supporting stock trading was likely reduced by electronic markets. Taxes are computed automatically, trading orders are no longer written by hand, transactions are recorded in the electronic tape, just like daily positions and holdings are netted electronically.

Figure 10 shows that trading automation slightly increased the employment of quants and financial analysts in broker-dealers, although estimates are imprecise and not statistically significant. One reason may be that firms with greater exposed to automation have higher propensity to outsource these services. Another reason is that, while Census employment counts are useful for this exercise, they are likely to suffer from large sampling error in narrow occupational cells, such as "Software Developers, Applications and Systems Software" in investment firms.

The employment of brokerage clerks decreases dramatically following Reg NMS. For each additional computer per worker, the employment of workers performing manual routine-based tasks related to stock trading reduces by almost 50%. This is a greater employment elasticity to automation compared to stock traders and in line with the decline of clerical employment in other industries due to automation.

### 7.3 Skill Premium

The financial sector has experienced a dramatic increase in pay and education level since the 1980s. Most of this trend is driven by a subset within finance, including traders. Reshef and Philippon (2012) show that while credit intermediation, insurance, and trading services had a wage premium of about 50% over the nonfarm private sector in 1970, average trading wages were 4-fold those in the wide economy by 2010 and credit and insurance wage premia remained relatively constant.

Various papers have proposed theoretical explanations for this surge in financial compensation, ranging from overinvestment in expertise (Glode et al. (2012)), to concentration of workers in the high end of the skill distribution (Glode and Lowery (2016), Célérier and Vallée (2019)) in financial firms and competition for talent (Thanassoulis (2012)). Trading in electronic markets involves a considerably higher level of skill and technical ability than trading did until the late 1990s. If electronic trading complements the skills of highly educated traders, one would expect the wage skill premium between this group and stockbrokers without college degree to widen after Reg NMS. I test formally for the presence of a skill-biased channel by running a difference-in-difference-in-differences (DDD) regression:

$$\begin{aligned}\ln\left(Wage_{ict}\right) = & \alpha_0 + \delta_0 \text{Post RegNMS}_t + \delta_1 \left(\text{Post RegNMS}_t \times \text{Skilled}_i\right) \\ & + \delta_2 \left(IT_c^{2004} \times \text{Post RegNMS}_t\right) + \delta_3 \left(IT_c^{2004} \times \text{Post RegNMS}_t \times \text{Skilled}_i\right) \\ & + \gamma X_{ict} + \lambda_t + \mu_c + \varepsilon_{ict}\end{aligned}$$

where the coefficient $\delta_3$ in the reduced-form equation measures how Reg NMS affected high-skill (college or more) brokers in areas with historical intensive IT use differentially from low-skill workers. The outcome is log hourly wage and personal characteristics in $X_{ict}$ include gender, experience (linear and squared), and number of children. If electronic trading is a skill-biased technology, we expect the wage differential to be positive, $\delta_3 > 0$.

The DDD model uses pooled census data instead of a longitudinal firm-worker panel as in the baseline model. To properly identify $\delta_3$, I rely on the stronger assumption that within county and netting out controlled observable characteristics, brokers in the repeated cross section do not differ systematically over time. The estimate is reported in column 4 of Table 7. The positive effect shows that Reg NMS increased hourly wages of high-skill workers in areas with an additional computer per broker by 9% compared to low-skilled workers. This translates as roughly $10,000 annually at the mean.

## 7.4 Robustness Checks

This subsection conducts a series of tests to verify the plausibility of the parallel trends and other possible model assumption violations, and whether the baseline model is robust to a different intensity measure. An analysis of the significance of alternative explanations, including the Great Recession and online brokerage platforms is delayed until Section (8).

In additional results, I interact county and time effects to allow for flexible trends potentially driving local broker employment. Second, I remove year dummies from (7.1) and add a linear time trend and a trend interacted with $IT_c^{2004}$. This specification tests whether the policy still affects employment after allowing for a common linear trend across counties. The estimate in column 2 of (7) is remarkably similar to the coefficient from the baseline model. Next, (3) interacts the linear trend with county fixed effects, in the following specification:

$$Employed_{ict} = \alpha_{0c} + \mu_c t + \delta \left( IT_c^{2004} \times \text{Post RegNMS}_t \right) + \gamma X_{ict} + \lambda_t + \varepsilon_{ict} \tag{3}$$

which allows counties with different levels of IT intensity to follow different trends. In other words, (3) nets out changes in local broker-dealer employment caused by Reg NMS from each county's (potential) own employment trend. Results are displayed in column 3 and again sustain the inference from my main estimates. Taken together, these specifications tests formally confirm that the parallel trends assumption is unlikely to be violated in my baseline model.

**Alternative intensity measure.** As an additional check, I use the broadband availability measure $\widetilde{IT_c^{2004}}$. While this measure is less relevant than the IT intensity using computers per desk worker, it tests for the importance of *minimum* technology in providing heterogeneous levels of local exposure to Reg NMS. Many broker-dealers occupy the same buildings to take advantage of pre-existing high-speed internet infrastructure. Back-end communication systems and networks in trading firms to access price feeds and co-location rights offered by exchanges require advanced internet services, which might make electronic trading adoption in areas with larger high-speed internet easier. Results in column 1 are in line with the baseline estimates.

**Placebo period.** Next, I verify whether pre-policy differences between firms in high IT areas and the ones in low IT counties might be driving the baseline employment results. A simple test for this is to "ignore" the introduction of Reg NMS by replicating the baseline model prior to 2005. Over 2001-2004, I consider 2004 as a placebo policy intervention (i.e. "Post RegNMS"$_t \equiv \mathbb{1}\{t \geq 2004\}$) and run DiD regressions up until Reg NMS became fully effective. Columns (1) through (3) in Table 8 confirm that potential observed and unobserved heterogeneity between broker-dealers in areas with varying degrees of IT intensity are unlikely to drive the employment effects I attribute to Reg NMS.

**Anticipatory IT investment.** A potential concern with the IT intensity measure is that if the county-level number of PCs per worker would reflect firms' ongoing shift toward electronic trading, values of $IT_c^{2004}$ might correlate with unobserved trends in technology upgrading. This would in turn exacerbate the effects on employment attributed to Reg NMS in my baseline model, since a county with high PC-worker ratio could already be automating trading at a faster rate.

The CI Technology Database offers a variable tracking the growth of a specific technology for every firm, which I denote by $\Delta IT_j^{fin}$. For example, if firm $j$ had 30 computers per worker in 2004, $\Delta IT_j^{fin} > 0$ indicates whether the firm had been increasing the number of computers until the observed 30 units. I test whether the trend in IT upgrading pre-2004 predicts employment growth in columns (4) and (5) of Table 8. The non-significant coefficients indicate that local trends in IT upgrading are uncorrelated with future employment changes.

# 8 Alternative Explanations

This section discusses and tests the role of two potentially confounding factors to my empirical design. First, the Great Recession exerted differential effects in local labor and housing markets, which could affect the demand for brokerage services or the supply-side of trading services to a greater extent in areas with higher pre-policy IT intensity. Second, the rise of online discount brokerage services that started in the early 2000s could also affect the demand of customers for retail and perhaps even institutional brokerage firms.

## 8.1 The Great Recession

The economic downturn during 2007-2009 impacted in particular housing markets and highly-leveraged financial institutions, to a great extent because of mortgage-backed securities and CDO holdings. At a high level, employment losses, credit crunch, and deterioration of household balance sheets during the Great Recession could all affect the demand or supply of brokerage services. One of the controls included in the baseline model — local stock market wealth — is a first attempt to control for spatial heterogeneity in shocks to individuals' income from stock market holdings relative to labor wages. The analysis below intends to capture several specific channels through which the Great Recession could bias my main results.

**Omitted variable bias in the treatment intensity measure.** The first test investigates the possibility that the pre-Reg NMS IT infrastructure measure correlates with unobservable characteristics that made the effects of the financial crisis particularly acute in more exposed areas.[14] Under the assumption that this potential omitted variable bias is not exclusive to broker-dealers, estimates in the first panel of Figure 11 provide exhaustive placebo-type regressions. Each coefficient captures how local employment in a given sector changes in areas with larger trader employment losses after Reg NMS. Although I keep the intervention year in these regressions as 2007, since Reg NMS has no impact on other sectors the "after" period may be interpreted as the confounding effect of the Great Recession picked up by the Reg NMS dummy, treating different areas given the IT measure.

Across almost 180 sectors, only 13 estimates are statistically significant. This indicates that areas with larger automation exposure in the investment industry do not disproportion-

[14] Perhaps high pre-existing IT investments were part of firm conduct that included over-leverage, even though IT levels in 2004 negatively correlate with prior trends in investment.

ately experience employment changes in other sectors, either because of local effects from the Great Recession or other systematic events around the implementation of Reg NMS. Another interpretation of these regressions is that there is no evidence that counties with high IT exposure have any particular employment drivers.

**Did the Great Recession accelerate trading automation?** The second panel of Figure 11 tests a more subtle possibility. Suppose that Reg NMS indeed led broker-dealers to automate and substitute labor for capital, resulting in stock trader employment losses, but this process was accelerated or intensified by the Great Recession. The possibility of recessions accelerating routine-biased technological change (Hershbein and Kahn (2018)) would imply that part of the effect or timing I attribute to Reg NMS stems from unrelated recessionary forces. To test this conjecture, I calculate industry-specific IT measures for each county and verify whether, for example, areas with higher IT levels in the healthcare sector experience faster employment changes in the industry post-2007. Out of 23 broad sectors, only one has a *positive* employment pattern after 2007 in counties with higher IT infrastucture in 2004. Taken together, these results point to a lack of evidence that industry-specific IT infrastructure measures correlate with subsequent changes in employment during the Financial Crisis.

**Other financial workers.** Given that Reg NMS should only directly affect broker-dealer individuals trading stocks, one could test to whether other financial workers plausibly unaffected by the provision also experienced similar employment losses during 2001-2015. The idea with this exercise is to a class of financial workers that could be affected *only through* the Great Recession to test whether the "post-policy" period is really picking up the effects from the financial crisis. I use local employment (at the county level) in the financial sector excluding security, commodity brokerage, and investment companies. The data use employed individuals between ages 18 and 64 working in the following industries: banking, saving institutions, credit unions, credit agencies, and insurance companies from March supplements of Current Population Surveys (CPS) from 2001-2015. Note that while this exercise is complementary to the difference-in-differences results in the previous section that compare stock traders to investment advisors, bond traders, and all other financial workers employed in broker dealers, here I consider all workers in any financial service.

Results in column (1) of Table 9 indicate that employment in the finance-wide industry actually increased post-Reg NMS in counties with higher historical presence of computers per worker. Of course, these effects should not be attributed to Reg NMS. Instead, they point out to a lack or even positive trend in employment of non-stockbroker workers during 2007-2015 relative to the 2001-2006 period. There is no reason to expect differential effects of the Great Recession for these workers compared to the Series 7 individuals used in the baseline analysis given that the Reg NMS channel through electronic trading is shut off for, say, real estate or insurance agents.

**Key Financial Crisis events.** Leveraging the high frequency and regular updates of FINRA records, an additional stringent analysis I conduct inspects employment trends following key events of the Great Recession. Figure 12 displays monthly changes in employment status of stock traders who were working in October 2007, when Reg NMS is fully implemented. These raw changes in employment intend to provide a visual inspection of potential clusters following, for example, the bankruptcy of Lehman Brothers.[15]

The figure shows that from 2006 to October 2007, monthly changes in stock trader employment followed relatively constant rates of 2%. The period incorporates many of the early signs of the financial crisis, including New Century's bankruptcy early 2007. From October 2007 to March 2008, prior to the failure of Bear Stearns, monthly employment changes increase, achieving almost 10% in February 2007. While the move also captures seasonality during the month, its magnitude is still larger than subsequent February observations. After that, around the collapse of IndyMac, Lehman Brothers, and Citigroup, and the historical Dow Jones drop, stock trader employment continues to decline at rates ranging from 2%-6% per month, without clear clusters other than typical seasonality. From 2010 and beyond, monthly changes in employment status of traders employed in October 2007 continue to decline at similar rates.

These aggregate patterns show that during most of the Financial Crisis, stock broker employment declined at relatively constant rates, without large movements following key supply-side events. The largest short-term employment decline occurs immediately after the full implementation of Reg NMS. Despite some of this movement being attributable to seasonality in the beginning of the year, there is little descriptive evidence that stock trader employment trends align with other events during the same period. For example, the drop in employment in January-February 2011 of 4.5%, well after the official end of the Great Recession, has the same magnitude as in the begining of 2009.

**Investment banks.** To formalize the points above, next I replicate the baseline stock trader employment model by excluding large investment banks — Goldman Sachs, Merrill Lynch, Morgan Stanley, JP Morgan, and Lehman Brothers. Dropping the *Big 5* in column (2) of Table 9 produces no changes in the estimate of interest, even though these institutions were particularly affected the the crisis (Longstaff (2010), Ivashina and Scharfstein (2010), Aragon and Strahan (2012)). Of course, the effects of the balance sheet deterioration from these banks spilled over and contaminated various financial institutions. While completely controlling for

[15]Even if such clusters exist, my empirical designs are only potentially contaminated by these events to the extent that their intensity correlates with 2004 levels of IT infrastructure or that they did not affect investment advisors, bond traders, and other financial workers.

such effects is not possible, the robustness of the baseline results to excluding those banks plausibly affected the most by the financial crisis lends further credibility to the role of Reg NMS in accounting for the employment dynamics of stockbrokers.

**Omitting New York.** Given that New York accounts for nearly 25% of stock traders in the US and the area was among the ones with highest pre-policy IT intensity levels, one might worry idiosyncratic factors related to the financial center drive my results. In column (3) of Table 9, I omit traders working at New York brokers, which result in estimated effects nearly identical to the ones when NYC is included.

**Housing crisis and household balance sheet.** Previous work by Mian et al. (2013) has shown that the 2006-2009 housing collapse affected consumption differentially across the US depending on the local composition of household balance sheets. One potential implication of this decline in housing net worth is that perhaps the demand for risky assets decreased to mitigate income effects. I use a repeat-sales home price index from the Federal Housing Finance Agency (FHFA) to answer whether the negative effects on stockbroker employment remain after controlling for the deterioration of home values. The estimate in column (4) remains unchanged relative to the baseline model.

## 8.2 Online Brokerage Services

To conclude the empirical analysis, an additional test checks the possibility that growth in local demand for online brokerage services impacted broker-dealer firm employment. Online brokerage firms, usually discount brokers, offer online infrastructure for individual investors to have access to financial markets without relying on traditional broker dealer firms. Analyzing the impact of this type of online financial service is challenging if such platforms do not provide granular data on costumer accounts over time and across space. Consider for instance E*Trade, one of the first and major online brokers in the US. E*Trade only publishes the aggregate annual number of active accounts in the US. Measuring the influence E*Trade on traditional broker-dealers requires the spatial allocation of these aggregate numbers.

I circumvent this issue by exploiting spatial variation in relative search traffic for "E*Trade" using Google Trends to allocate US E*Trade accounts to each county in my sample. Other papers have used Google Trends in distinct contexts to instrument for local demand or awareness for certain services, such as AirBnb (Barron et al. (2018)). For each year, Google assigns a value of 100 to the MSA with the largest number of searches of the term "E*Trade" and then ranks other MSAs relative to the top search area. This ranking generates spatial variation in the intensity of the "interest" for the searched term, which I then use to allocate aggregate brokerage accounts available from E*Trade 10-K forms to each county in my analysis. In column (5) of Table 9, including this local measure of demand for online brokerage services as an additional control in the baseline specification does not affect the estimated effects of Reg NMS.

# 9 Conclusion

The migration to electronic markets and trading automation in the early 2000s was the most important technological change in the history of stock markets. The trading industry made investments in IT physical infrastructure and software of over $100 billion and markets became dominated by algorithms and speed competition. This paper studies how automation affected broker-dealer firms and stock traders, investigating winners and losers in new financial markets.

I estimate an average return to automation to trading firms of $98,000 in annual net profits for each additional computer per worker. In the aggregate, even relatively small investments in technology lead to an increase in industry local profits of $1 million. Returns to automation accrue unevenly. The same technology investment in broker-dealers with total assets above $80 billion are anywhere from $50,000 to $380,000 more profitable than in a $100 million asset firm. As a consequence, profit concentration in large firms increases 4 percentage points. Automation also affected the composition of trading firms along two margins. First, fewer broker-dealers enter the investment industry. In addition, large and small employers, who are more likely to cater to high net worth individuals and engage in proprietary trading, experience higher survival rates.

I also document large displacement effects on stock traders, whose job task content changed dramatically with electronic trading. I find that these financial professionals become from 2 to 20 percentage points less likely to remain employed, even when compared to other workers in market segments that did not experience automation. This large elasticity of employment with respect to computer capital aligns with extensive-margin adjustments of labor when workers perform cognitive and manual tasks that can be automated (Autor et al. (2003)).

Overall, my findings offer evidence supporting that large trading firms, who provide services to a small portion of investors, appear to have benefited from trading automation. An avenue for future research is to investigate whether small investors are necessarily worse-off. New trading and data technologies increased market access and cheapened fees investors face. If the firms who failed to capture the benefits from automation predominantly served this group of individuals, investors may be better off by switching to different brokers or taking advantage of new investment products made possible by electronic markets.

# References

Acemoglu, Daron and David Autor (2011) "Skills, tasks and technologies: Implications for employment and earnings," in *Handbook of Labor Economics*, Vol. 4: Elsevier, pp. 1043–1171.

Acemoglu, Daron and Pascual Restrepo (2019) "Automation and New Tasks: How Technology Displaces and Reinstates Labor," *Journal of Economic Perspectives*, Vol. 33, No. 2, pp. 3–30.

——— (2020) "Robots and jobs: Evidence from US labor markets," *Journal of Political Economy*, Vol. 128, No. 6, pp. 2188–2244.

Adrian, Tobias, Erkko Etula, and Tyler Muir (2014) "Financial Intermediaries and the Cross-Section of Asset Returns," *The Journal of Finance*, Vol. 69, No. 6, pp. 2557–2596.

Aghion, Philippe, Céline Antonin, Simon Bunel, and Xavier Jaravel (2020) "What are the labor and product market effects of automation? New Evidence from France," *CEPR Discussion Paper No. DP14443*.

Aquilina, Matteo, Eric Budish, and Peter O'Neill (Forthcoming) "Quantifying the High-Frequency Trading "Arms Race"," *Quarterly Journal of Economics*.

Aragon, George O. and Philip E. Strahan (2012) "Hedge funds as liquidity providers: Evidence from the Lehman bankruptcy," *Journal of Financial Economics*, Vol. 103, No. 3, pp. 570 – 587.

Autor, David H., Frank Levy, and Richard J. Murnane (2003) "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics*, Vol. 118, No. 4, pp. 1279–1333.

Baron, Matthew, Jonathan Brogaard, and Andrei Kirilenko (2012) "The trading profits of high frequency traders," *Unpublished manuscript*.

Barron, Kyle, Edward Kung, and Davide Proserpio (2018) "The Effect of Home-Sharing on House Prices and Rents: Evidence from Airbnb," *SSRN Electronic Journal*.

Beaudry, Paul and Ethan Lewis (2014) "Do Male-Female Wage Differentials Reflect Differences in the Return to Skill? Cross-City Evidence from 1980-2000," *American Economic Journal: Applied Economics*, Vol. 6, No. 2, pp. 178–94.

Biais, Bruno, Thierry Foucault, and Sophie Moinas (2015) "Equilibrium fast trading," *Journal of Financial Economics*, Vol. 116, No. 2, pp. 292 – 313.

Bloom, Nicholas, Raffaella Sadun, and John Van Reenen (2012) "Americans Do IT Better: US Multinationals and the Productivity Miracle," *American Economic Review*, Vol. 102, No. 1, pp. 167–201.

Bond, Philip and Vincent Glode (2014) "The Labor Market for Bankers and Regulators," *Review of Financial Studies*, Vol. 27, No. 9, pp. 2539–2579.

Budish, Eric, Peter Cramton, and John Shim (2015) " The High-Frequency Trading Arms Race: Frequent Batch Auctions as a Market Design Response," *Quarterly Journal of Economics*, Vol. 130, No. 4, pp. 1547–1621.

Budish, Eric, Robin S Lee, and John J Shim (2019) "A Theory of Stock Exchange Competition and Innovation: Will the Market Fix the Market?" Working Paper 25855, National Bureau of Economic Research.

Card, David (1992) "Using Regional Variation in Wages to Measure the Effects of the Federal Minimum Wage," *Industrial and Labor Relations Review*, Vol. 46, No. 1, pp. 22–37.

Célérier, Claire and Boris Vallée (2019) "Returns to Talent and the Finance Wage Premium," *Review of Financial Studies*, Vol. 32, No. 10, pp. 4005–4040.

Chao, Yong, Chen Yao, and Mao Ye (2018) "Why Discrete Price Fragments U.S. Stock Exchanges and Disperses Their Fee Structures," *Review of Financial Studies*, Vol. 32, No. 3, pp. 1068–1101.

Chodorow-Reich, Gabriel, Plamen T Nenov, and Alp Simsek (2021) "Stock market wealth and the real economy: A local labor market approach," *American Economic Review*, Vol. 111, No. 5, pp. 1613–57.

Colliard, Jean-Edouard and Thierry Foucault (2012) "Trading Fees and Efficiency in Limit Order Markets," *Review of Financial Studies*, Vol. 25, No. 11, pp. 3389–3421.

Egan, Mark, Gregor Matvos, and Amit Seru (2019) "The Market for Financial Adviser Misconduct," *Journal of Political Economy*, Vol. 127, No. 1, pp. 233–295.

Farboodi, Maryam, Adrien Matray, Laura Veldkamp, and Venky Venkateswaran (2020) "Where Has All the Data Gone?" Working Paper 26927, National Bureau of Economic Research.

Glode, Vincent, Richard C. Green, and Richard Lowery (2012) "Financial Expertise as an Arms Race," *Journal of Finance*, Vol. 67, No. 5, pp. 1723–1759.

Glode, Vincent and Richard Lowery (2016) "Compensating Financial Experts," *Journal of Finance*, Vol. 71, No. 6, pp. 2781–2808.

Haslag, Peter H and Matthew Ringgenberg (2016) "The causal impact of market fragmentation on liquidity," in *Fourth Annual Conference on Financial Market Regulation*.

Hendershott, Terrence and Pamela C. Moulton (2011) "Automation, speed, and stock market quality: The NYSE's Hybrid," *Journal of Financial Markets*, Vol. 14, No. 4, pp. 568 – 604.

Hershbein, Brad and Lisa B. Kahn (2018) "Do Recessions Accelerate Routine-Biased Technological Change? Evidence from Vacancy Postings," *American Economic Review*, Vol. 108, No. 7, pp. 1737–72.

Ivashina, Victoria and David Scharfstein (2010) "Bank lending during the financial crisis of 2008," *Journal of Financial Economics*, Vol. 97, No. 3, pp. 319 – 338.

Jain, Pankaj (2005) "Financial Market Design and the Equity Premium: Electronic versus Floor Trading," *Journal of Finance*, Vol. 60, No. 6, pp. 2955–2985.

Kwan, Amy, Ronald Masulis, and Thomas H. McInish (2015) "Trading rules, competition for order flow and market fragmentation," *Journal of Financial Economics*, Vol. 115, No. 2, pp. 330–348.

Longstaff, Francis A. (2010) "The subprime credit crisis and contagion in financial markets," *Journal of Financial Economics*, Vol. 97, No. 3, pp. 436 – 450.

MacKenzie, Donald (2021) *Trading at the Speed of Light: How Ultrafast Algorithms Are Transforming Financial Markets*: Princeton University Press.

Maggio, Marco Di, Mark L Egan, and Francesco Franzoni (2019) "The Value of Intermediation in the Stock Market," Working Paper 26147, National Bureau of Economic Research.

Menkveld, Albert J. (2016) "The economics of high-frequency trading: Taking stock," *Annual Review of Financial Economics*, Vol. 8, No. 1, pp. 1–24.

Mian, Atif, Kamalesh Rao, and Amir Sufi (2013) "Household Balance Sheets, Consumption, and the Economic Slump," *Quarterly Journal of Economics*, Vol. 128, No. 4, pp. 1687–1726.

Mihet, Roxana (2020) "Financial innovation and the inequality gap," *Working Paper*.

O'Hara, Maureen (2015) "High frequency market microstructure," *Journal of Financial Economics*, Vol. 116, No. 2, pp. 257 – 270.

O'Hara, Maureen and Mao Ye (2011) "Is market fragmentation harming market quality?" *Journal of Financial Economics*, Vol. 100, No. 3, pp. 459 – 474.

Pagnotta, Emiliano S. and Thomas Philippon (2018) "Competing on Speed," *Econometrica*, Vol. 86, No. 3, pp. 1067–1115.

Philippon, Thomas (2015) "Has the US Finance Industry Become Less Efficient? On the Theory and Measurement of Financial Intermediation," *American Economic Review*, Vol. 105, No. 4, pp. 1408–38.

Raman, Vikas, Michel A Robe, and Pradeep K Yadav (2017) "The Third Dimension of Financialization: Electronification, Intraday Institutional Trading, and Commodity Market Quality," *WBS Finance Group Research Paper*.

Reshef, Ariell and Thomas Philippon (2012) "Wages and Human Capital in the U.S. Finance Industry: 1909–2006*," *Quarterly Journal of Economics*, Vol. 127, No. 4, pp. 1551–1609.

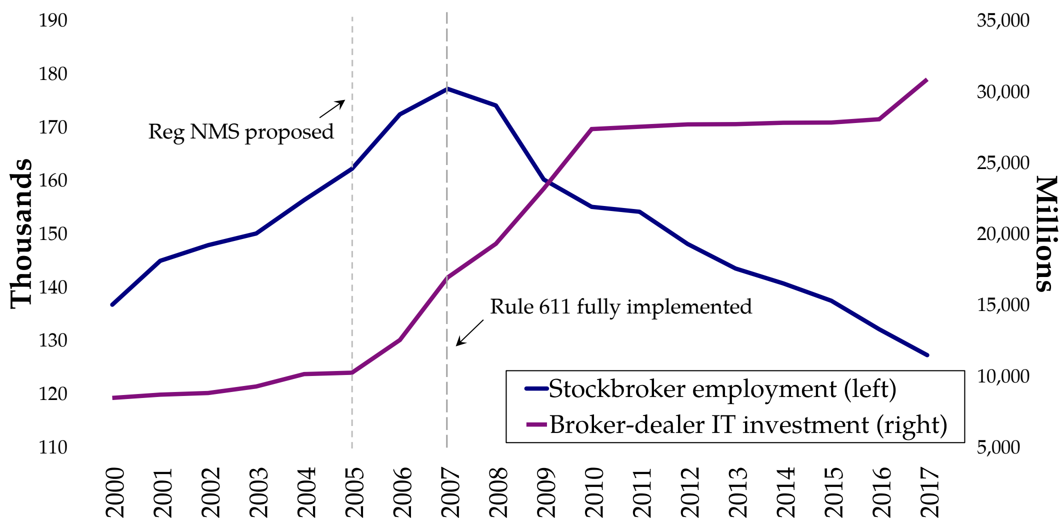
Shkilko, Andriy and Konstantin Sokolov (2020) "Every Cloud Has a Silver Lining: Fast Trading, Microwave Connectivity, and Trading Costs," *Journal of Finance*, Vol. 75, No. 6, pp. 2899–2927.

Spatt, Chester (2018) "The new realities of market structure and liquidity: Where have we been? Where are we going?" in *Public Policy & Financial Economics: Essays in Honor of Professor George G Kaufman for His Lifelong Contributions to the Profession*: World Scientific, pp. 247–263.

Stoll, Hans R. (2006) "Electronic Trading in Stock Markets," *Journal of Economic Perspectives*, Vol. 20, No. 1, pp. 153–174.

Thanassoulis, John (2012) "The Case for Intervening in Bankers' Pay," *Journal of Finance*, Vol. 67, No. 3, pp. 849–895.

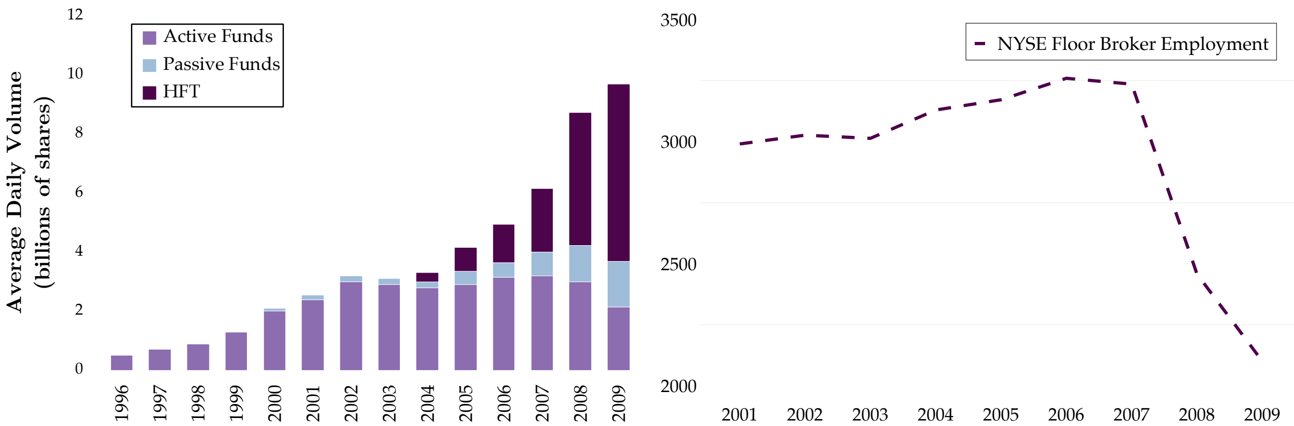
Tse, Yiuman and Tatyana V. Zabotina (2001) "Transaction Costs and Market Quality: Open Outcry Versus Electronic Trading," *Journal of Futures Markets*, Vol. 21, No. 8, pp. 713–735.




*Following Reg NMS, IT investment in US trading firms increased three-fold, while stock trader employment fell by almost 60,000 jobs.*

***Notes:*** This figure compares the evolution of IT capital stock (in the securities, commodities, and investments industry) and employment of stock traders in US broker-dealers. The employment series aggregates all employed individuals registered in FINRA's Central Registration Depository (CRD) with an active registration trading stocks in a given year. Dashed lines indicate Regulation NMS's rollout period, with full implementation in 2007. The IT capital stock series is constructed following in Reshef and Philippon (2012), except that the series plotted is not normalized by other sectors.

**Figure 1:** Trends in Jobs and Technology Capital in Trading



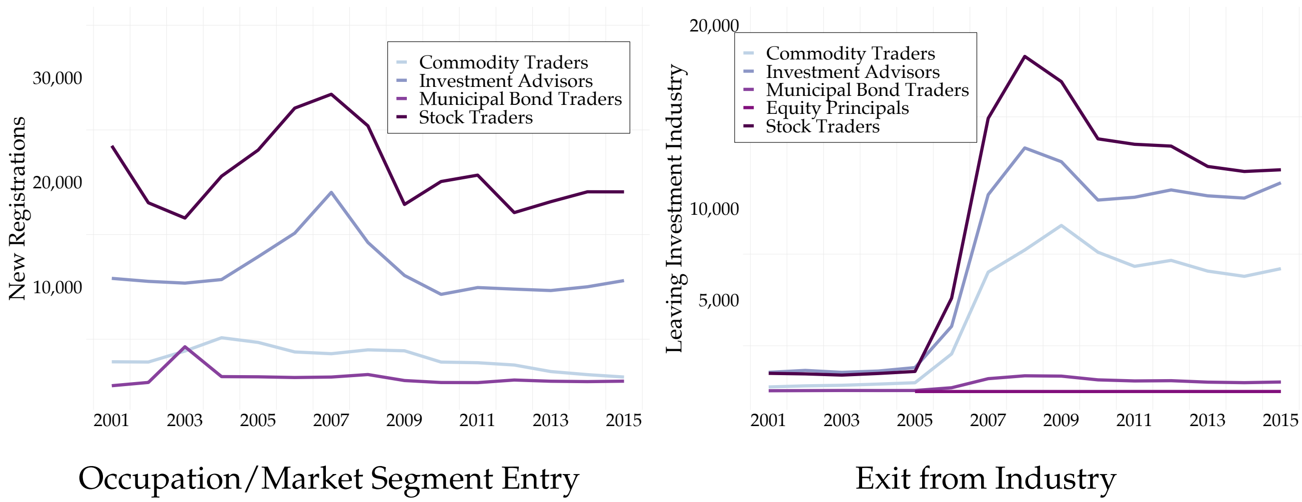

Stock Trading Volume by Activity

Number of Floor Brokers at NYSE

**Left:** *High-frequency trading (HFT) accounted for over 60% of daily volume traded in US stocks in 2009, more than doubling total market output since 2004.* **Right:** *Following the introduction of the Hybrid Market at NYSE, floor broker employment sharply declined.*

***Notes:*** The figure on the left shows data compiled by Tabb Group and Credit Suisse on the distribution of average stock traded volume by market participant segment. Active and passive funds include money managers and investors. High-frequency traders are a subset of algorithmic trading (AT), and provide an underestimate of the contribution of electronic submission and automated quoting and executing, some of which are not considered "high-frequency". US daily traded volume in 2009 was over 10 billion shares. The figure on the right plots data extracted from FINRA's CRD database, as described in the main text. The series is constructed using individuals holding a valid Series 25 license, known as "*NYSE Trading Assistant Exam*", which was required from trading assistants (post and booth clerks) at NYSE's trading floor. FINRA records show when the individual had employment terminated, left the securities industry, or changed market segment or occupation. The series thus tracks annual counts of unique NYSE floor brokers. For a visual depiction, see Figure A.1.

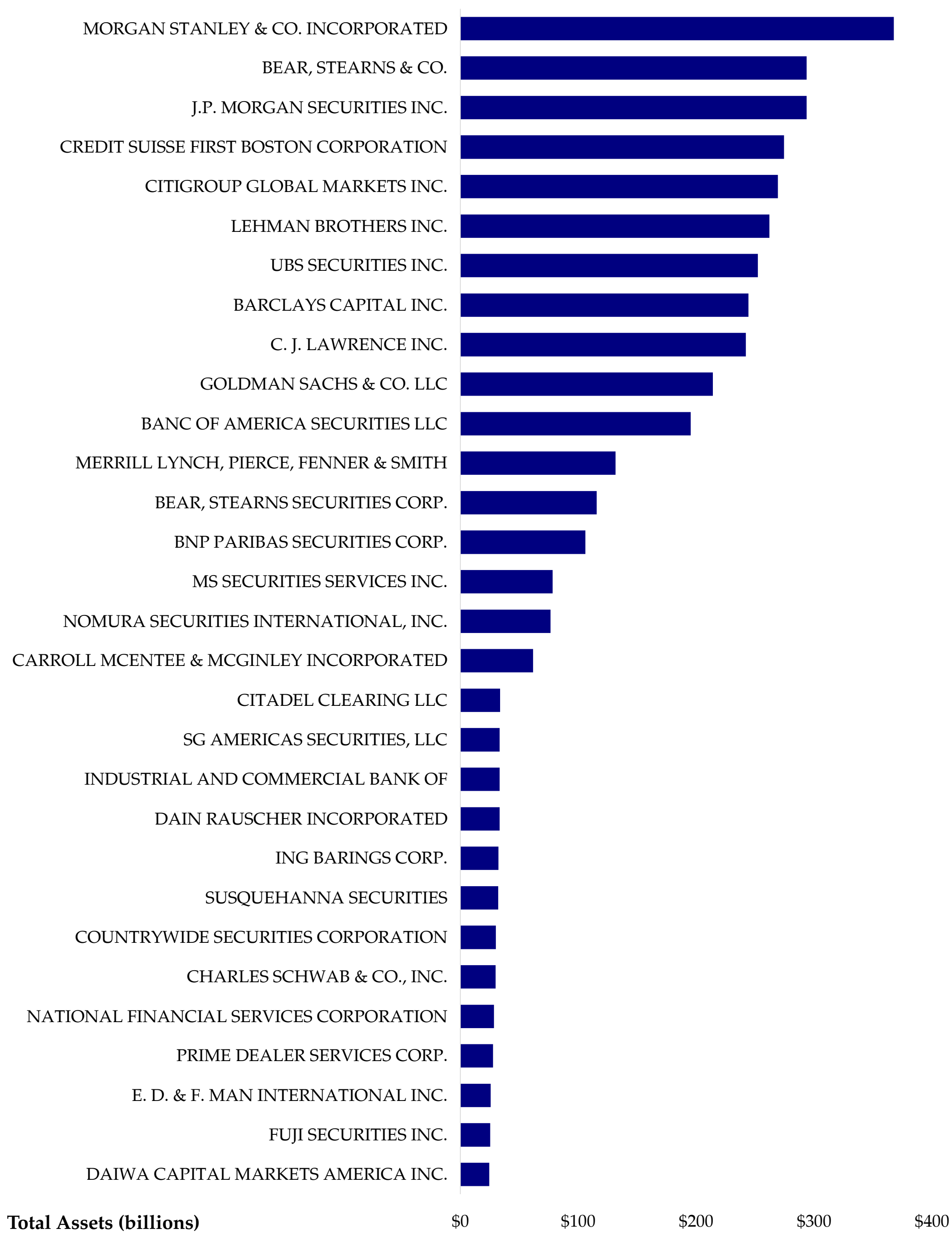
**Figure 2:** Growth in US Stock Trading Activity and Employment of NYSE Floor Brokers




**Left:** *20,000 new stock traders have entered the industry a year since 2009.* **Right:** *Stock traders left the investment industry at historically high numbers starting in 2005.*

***Notes:*** These figures compare industry entry and exit of stock traders to several categories of other workers in the investment industry. Entry is measured by the year an individual obtains the necessary license to trade or work in the referred market segment, combined with a valid employment status. Exit is measured as the year an individual permanently leaves any segment in equities industry, where I assign the type of trader to the most recent license she obtained before leaving the sector. Data come from FINRA's CRD repository. Details on sample construction and definitions of each group of trader can be found in the main text.

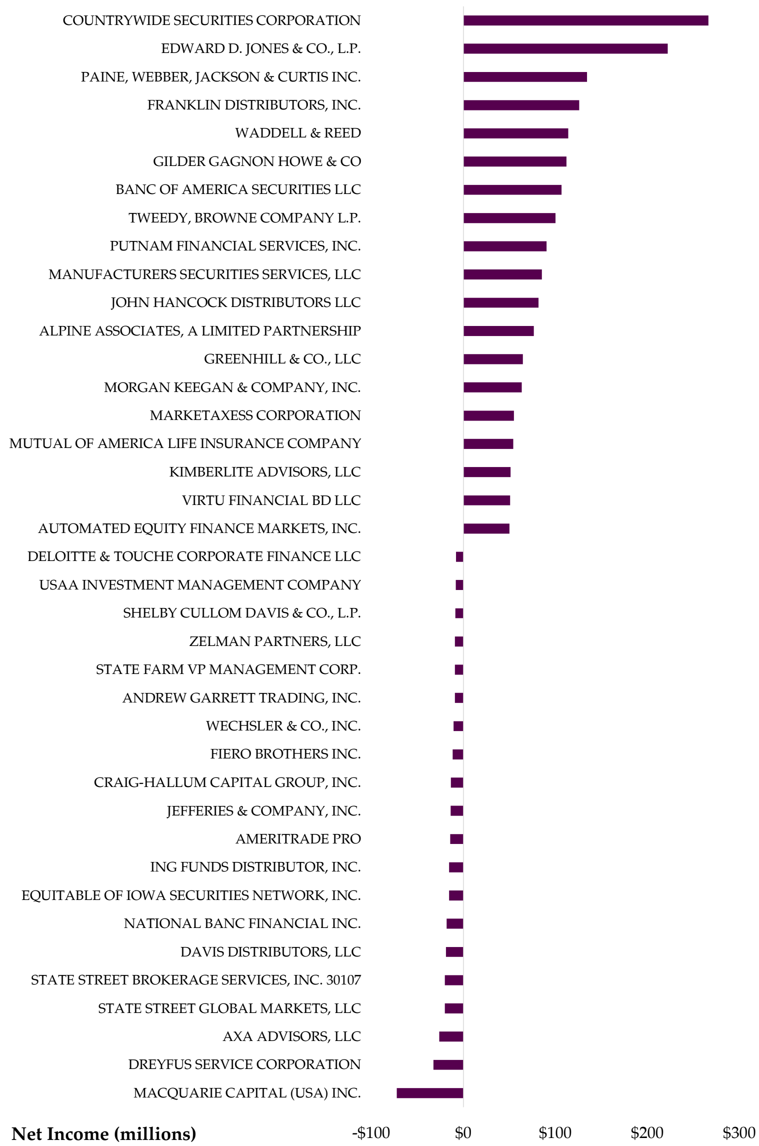
**Figure 3:** Occupation Entry and Investment Industry Exit




*Book size of the trading division from large investment firms tops $300 billion, largely corresponding to cash on hand, market positions, and receivables from clearing broker and customers.*

***Notes:*** The figure shows total asset values for the 30 largest broker-dealers in US equities markets. Bars represent the average of annual book sizes from 2002—2014. Micro data is constructed from forms X-17A-15 submitted by every broker-dealer every year, extracted, processed, and parsed following the details in the main text. For comparison, the total value of assets for broker-dealers was $4 trillion over the period.

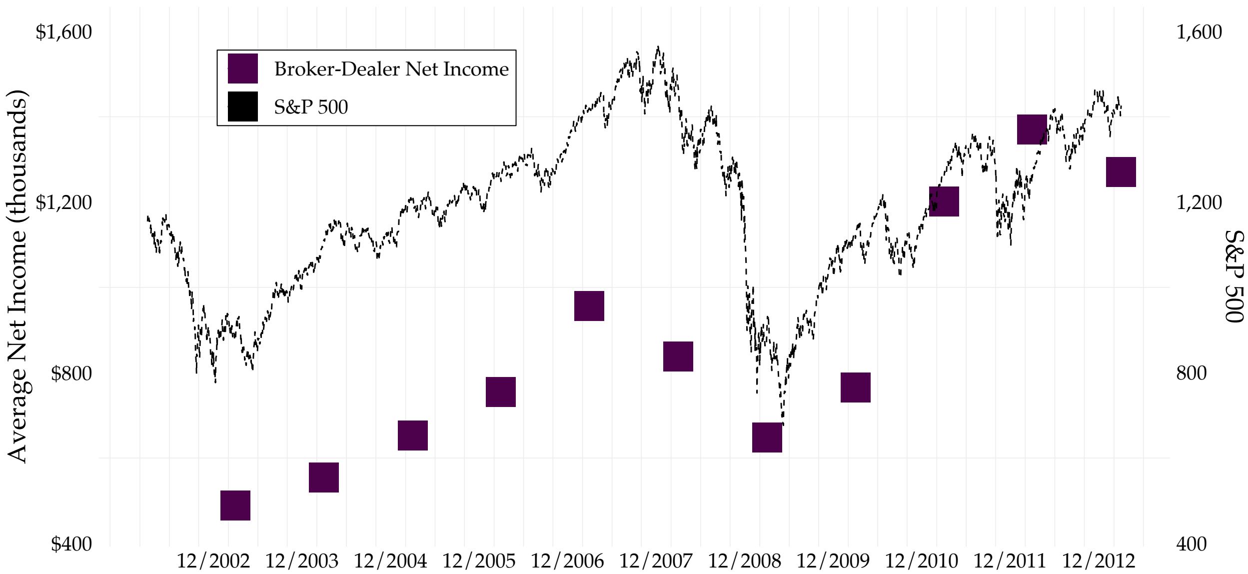
**Figure 4:** Total Assets of Top Broker-Dealer Firms




*The average distribution of broker-dealer net income ranges from a loss of over $100 million to $300 million in profit.*

***Notes:*** The figure shows net income of selected broker-dealers with the best average gains and losses from 2002—2014. Micro data is constructed from forms X-17A-15 submitted by every broker-dealer every year, extracted, processed, and parsed following the details in the main text. Common lines in broker-dealers statement of operations/income include commissions, investment brokerage fees, advisory and transaction services, private placements, incentive fees, research revenue, handling and processing fees, interest and dividends as revenue sources, and commissions, employee compensation and benefits, clearing and transaction costs, advertising, communications and technology, membership and clearing fees, travel and entertainment, regulatory fees and expenses, and office and occupancy expenses as main sources of operating expenses.

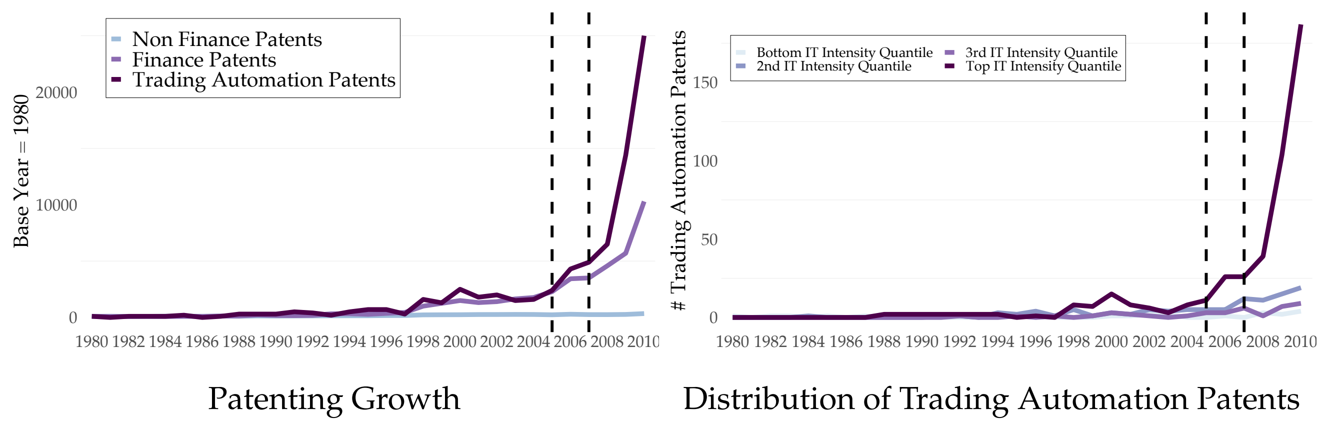
**Figure 5:** Range of Broker-Dealer Performance




*Average broker-dealer performance is highly correlated with market returns.*

***Notes:*** The figure plots annual averages of broker-dealer net income from individual X-17A-5 filings extracted, processed, and parsed following the details in the main text. Common lines in broker-dealers statement of operations/income include commissions, investment brokerage fees, advisory and transaction services, private placements, incentive fees, research revenue, handling and processing fees, interest and dividends as revenue sources, and commissions, employee compensation and benefits, clearing and transaction costs, advertising, communications and technology, membership and clearing fees, travel and entertainment, regulatory fees and expenses, and office and occupancy expenses as main sources of operating expenses. The other series shows daily closings of the S&P 500.

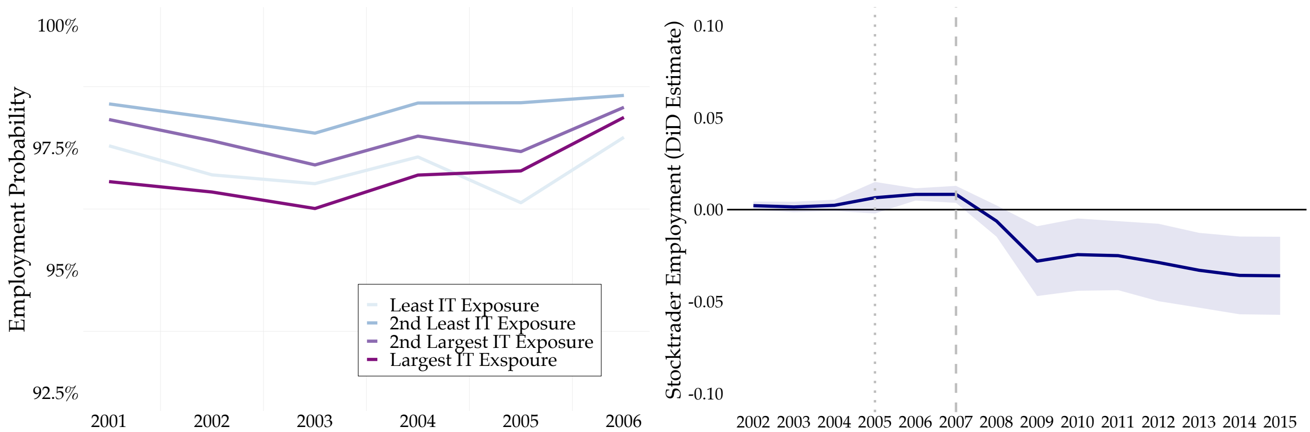
**Figure 6:** Broker-Dealer Profitability and Stock Market Return




**Left:** *Trading automation patenting grew much faster than patents in overall finance or in other sectors.* **Right:** *The growth in trading automation patenting occurred mostly in counties with high pre-existing IT infrastructure.*

***Notes:*** The left panel shows the growth of i) trading automation patents, ii) finance industry patents, and iii) non-finance sector patents in the US with 1980 as the base year for counties with broker-dealer firms. The figure on the right zooms in on trading automation patents and plots growth trends according to different levels of local IT exposure.

**Figure 7:** Trading Automation, Overall Finance, & Non-Finance Patents




Pre-Trends in Stock Trader Employment

Estimated Effect of Automation

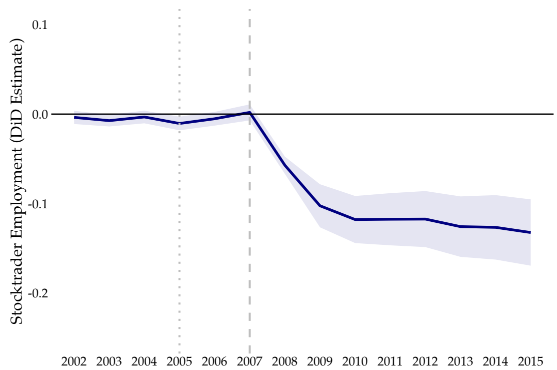
**Left:** *Employment propensities of stock traders in areas with high IT exposure followed similar trends relative to traders in areas with low exposure.* **Right:** *For each additional PC/worker before Reg NMS, stock traders become 2 p.p. less likely to be employed on average.*

***Notes:*** The first panel shows pre-trends in the probability of employment of stock traders who worked in 2007. Each line represents the average outcome in areas with different degrees of exposure to trading automation. The second plot shows dynamic difference-in-differences estimates of the model

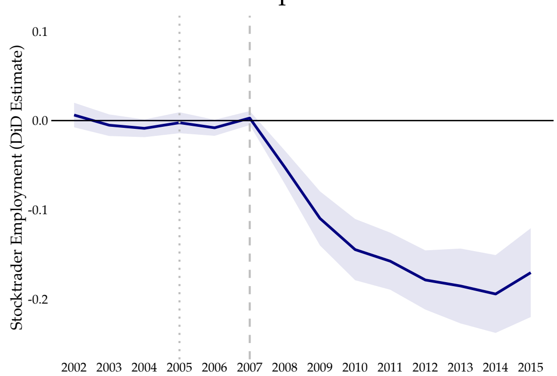
$$\Pr(Employed = 1)_{ict} = \alpha_0 + \sum_{k=2001}^{2015} \delta_k \left( IT_c^{2004} \times \mathbb{1}\{k = t\} \right) + \gamma X_{ict} + \lambda_t + \mu_c + \varepsilon_{ict}$$

which compares the probability of employment of stock traders exposed to different degrees of IT infrastructure. Shaded areas plot 95% confidence intervals obtained from standard errors clustered at the county level. The first dashed line represents the introduction of Reg NMS in 2005, while the second shows the regulation's full implementation in 2007. Data come from FINRA's Central Central Registration Depository (CRD).

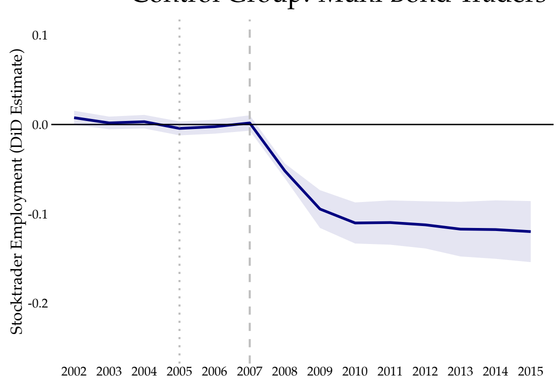
**Figure 8:** Impact of Trading Automation on Stockbroker Employment




Control Group: Investment Advisors




Control Group: Muni Bond Traders




Control Group : All Non-Stock Traders

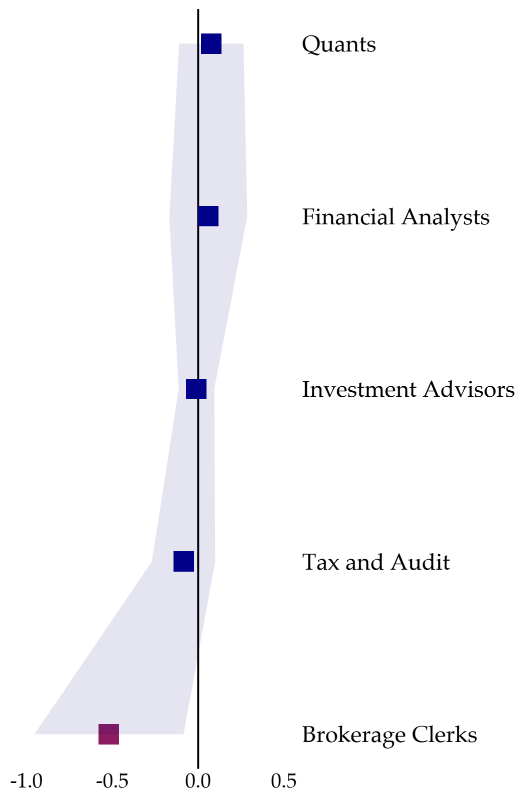
*Following Reg NMS, stock traders were 10-20 percentage points less likely to be employed than investment advisors, municipal bond traders, or any other financial professional not trading stocks working for broker-dealers*

***Notes:*** These figures show DiD estimates of the model

$$\Pr(Employed = 1)_{ict} = \alpha_0 + \sum_{k=2001}^{2015} \delta_k \left(\text{Stock Trader}_{ict} \times \mathbb{1}\left\{k = t\right\}\right) + \gamma X_{ict} + \lambda_t + \mu_c + \varepsilon_{ict}$$

which compares the probability of employment of stock traders to other financial workers employed at broker-dealers in the same area. Shaded areas plot 95% confidence intervals obtained from standard errors clustered at the county level. The first dashed line represents the introduction of Reg NMS in 2005, while the second shows the regulation's full implementation in 2007. Data come from FINRA's Central Central Registration Depository (CRD). For definitions of treatment and control groups, see main text.

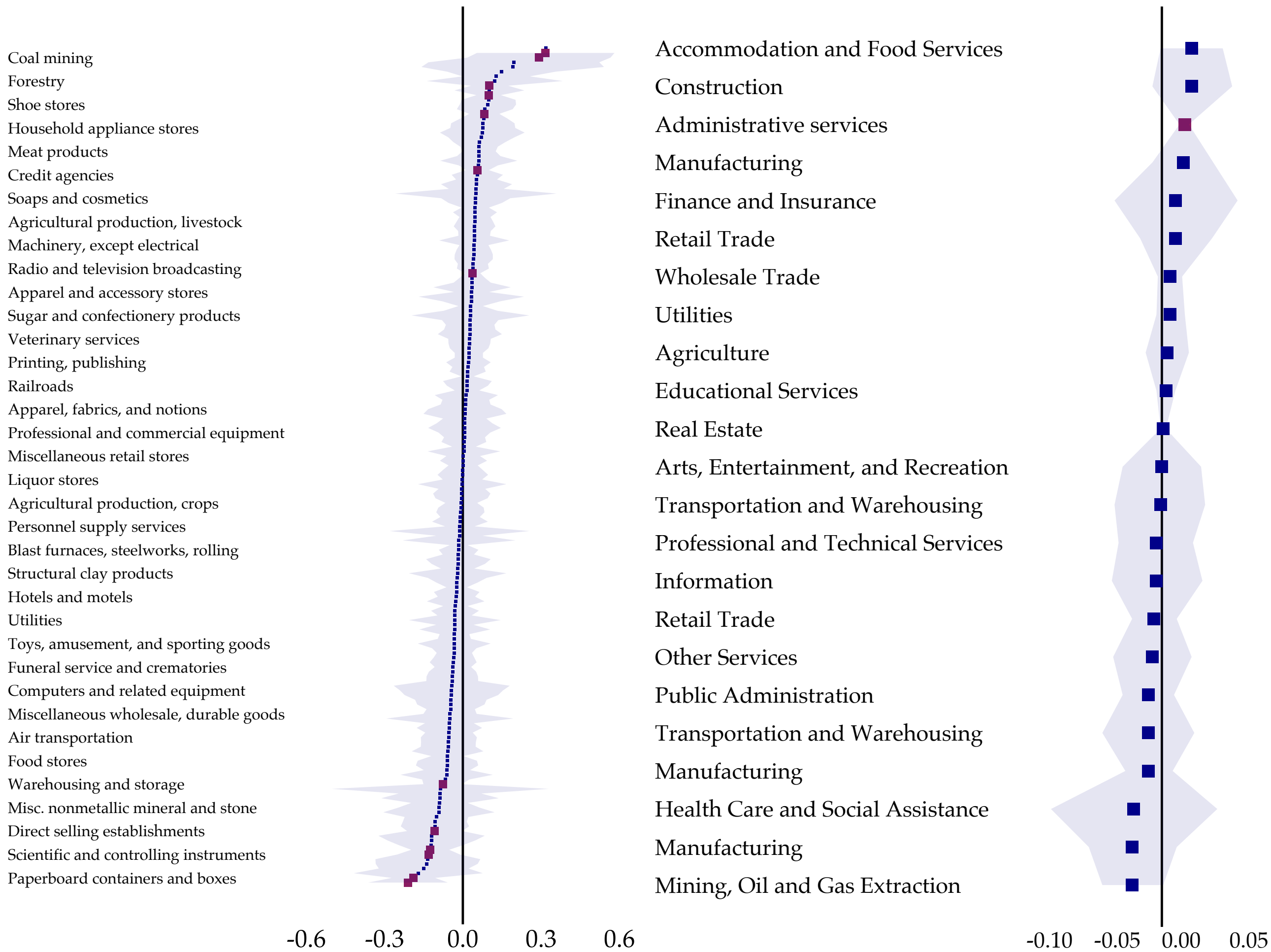
**Figure 9:** Impact on Stockbroker Employment vs. Other Investment Workers




*Broker-dealer employment of other workers remained relatively constant following trading automation, except for workers performing clerical tasks related to manual stock trading*

***Notes:*** These figures shows difference-in-differences estimates of county-level log employment of five occupational groups — quants, broadly encompassing computer and software engineers, programmers, and other IT professionals, financial analysts, investment advisors, tax and audit professionals, and brokerage clerks — on the 2004 IT infrastructure and Reg NMS.

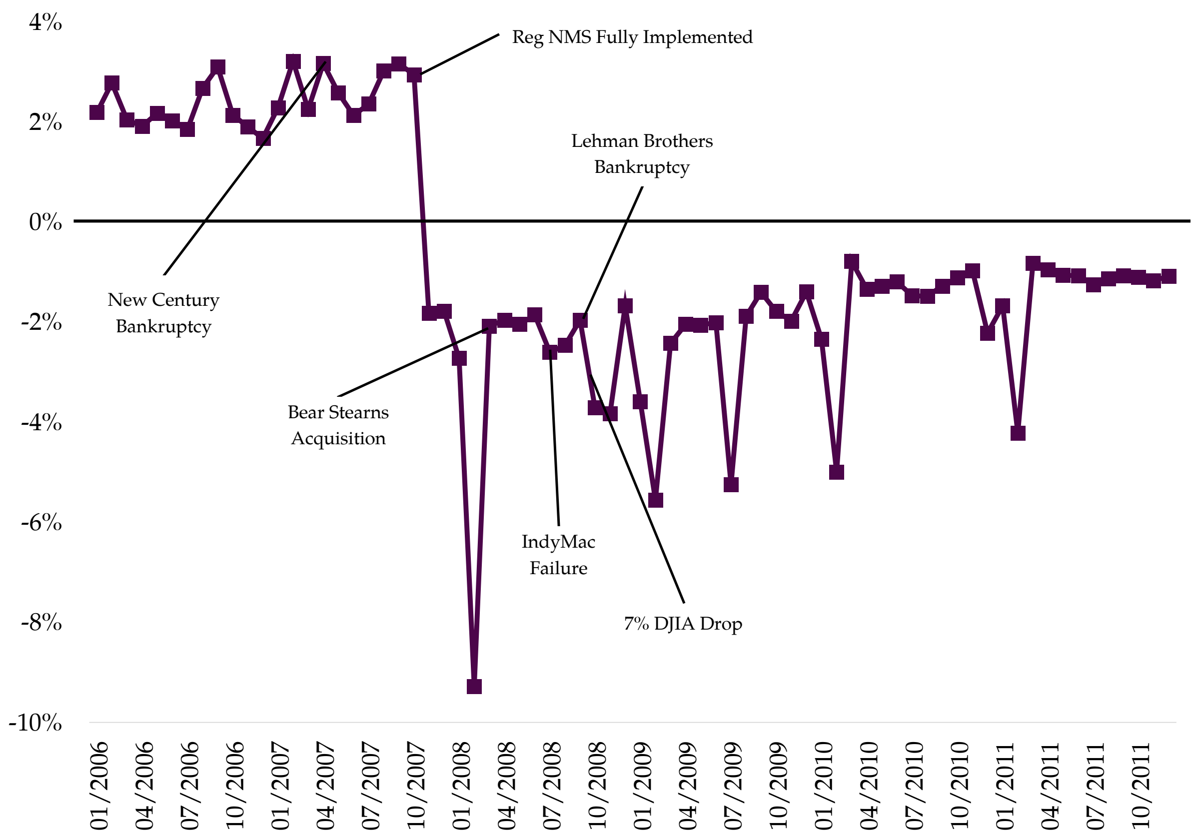
**Figure 10:** Impact on Employment of Other Broker-Dealer Workers




*Employment patterns across several industries show no association between pre-existing IT infrastructure and the Great Recession*

***Notes:*** The figure on the left plots placebo-style coefficients across 180 sectors from regressions of county-level (log) employment in each sector on the treatment variable $\left(IT_c^{2004} \times \text{Post RegNMS}_t\right)$, where Post RegNMS$_t$ is a dummy equal to one after 2006 and $IT_c^{2004}$ is the PC per worker measure in the investment industry in 2004. The second figure runs similar regressions, except that I calculate an industry-specific IT intensity within each county for all $s = 1, ..., 23$ broad sectors depicted, $IT_{c,s}^{2004}$. Only selected labels are plotted in the first figure. Estimates in purple are significant at 5%. County-level employment comes from the 2000 Census and annual American Community Surveys (ACS) annual samples after that. The estimation period is 2000-2015. Standard errors are clustered at the county-level.

**Figure 11:** Placebo Employment Regressions




*Employment rates of stock traders working in October 2007 change on average 2% month-over-month prior to the full implementation of Reg NMS and 6% after October. Changes in employment are seasonal and relatively stable around key events of the Great Recession. The largest short-term decrease in employment follows the implementation of the regulation*

***Notes:*** The figure shows monthly changes of stock trader employment in the US. The sample tracks the employment status of stock traders working in October 2007, when Reg NMS became fully active. Data come from FINRA's Central Central Registration Depository (CRD).

**Figure 12:** Stock Trader Employment Rates During Key Events of the Financial Crisis

**Table 1:** Where do Stock Traders Work?

| County | Major City | Stock Trader Employment | % Overall Employment | IT intensity rank (Out of 287) |
|---|---|---|---|---|
| *Panel A. 2004* | | | | |
| New York, NY | New York City | 55,276 | 24% | 3 |
| Atlantic, NJ | Atlantic City | 17,056 | 7% | 117 |
| Hennepin, MN | Minneapolis | 11,671 | 5% | 44 |
| Hudson, NJ | Jersey City | 9,385 | 4% | 30 |
| Los Angeles, CA | Los Angeles | 7,444 | 3% | 145 |
| Cook, IL | Chicago | 7,154 | 3% | 52 |
| Suffolk, MA | Boston | 6,527 | 3% | 5 |
| Providence, RI | Providence | 5,471 | 2% | 40 |
| San Mateo, CA | San Mateo | 4,872 | 2% | 56 |
| Fulton, GA | Atlanta | 4,532 | 2% | 4 |
| *Panel B. 2009* | | | | |
| New York, NY | New York City | 44,636 | 20% | 3 |
| Atlantic, NJ | Atlantic City | 15,691 | 7% | 117 |
| Hudson, NJ | Jersey City | 10,177 | 4% | 30 |
| Dauphin, PA | Harrisburg | 10,020 | 4% | 80 |
| Atlantic, NJ | Atlantic City | 8,728 | 4% | 117 |
| Hennepin, MN | Minneapolis | 7,472 | 3% | 44 |
| Los Angeles, CA | Los Angeles | 7,247 | 3% | 145 |
| Lake, IL | Waukegan | 6,614 | 3% | 230 |
| Hampden, MA | Springfield | 5,286 | 2% | 20 |
| Suffolk, MA | Boston | 4,914 | 2% | 5 |
| Cook, IL | Chicago | 4,670 | 2% | 52 |

***Notes:*** This table shows the largest employment centers of stock traders in the US and the pre-existing IT infrastructure in those areas. The IT intensity rank measures the average number of computer per office worker in firms across the entire investment industry in 2004. Stock traders are individuals currently registered and employed to trade stocks professionally, holding a valid Series 7 license without licenses to work in other market segments.

**Table 2:** Largest Employers in the Investment Industry

| | Stock Traders | | All Investment Workers | |
|---|---|---|---|---|
| | 2004 | 2015 | 2004 | 2015 |
| EDWARD D. JONES & CO., L.P. | 8,952 | 2,592 | 10,831 | 18,835 |
| SALOMON SMITH BARNEY, INC. | 7,733 | 3,290 | 22,184 | 8,127 |
| MERRILL LYNCH, PIERCE, FENNER & SMITH, INC. | 9,029 | 5,183 | 34,211 | 35,045 |
| AMERICAN EXPRESS FINANCIAL ADVISORS | 5,209 | 3,591 | 14,946 | 14,854 |
| IDS LIFE INSURANCE COMPANY | 4,981 | * | 14,439 | * |
| A. G. EDWARDS & SONS, INC. | 4,170 | ** | 8,823 | ** |
| GOLDMAN SACHS & CO. | 3,318 | 3,720 | 5,810 | 8,859 |
| WELLS FARGO ADVISORS, LLC | 3,225 | 3,881 | 14,654 | 28,688 |
| CHARLES SCHWAB & CO., INC. | 2,865 | 2,168 | 6,744 | 8,263 |
| LEHMAN BROTHERS INC. | 2,790 | * * * | 4,107 | * * * |
| UBS FINANCIAL SERVICES INC. | 2,732 | 1,659 | 11,305 | 13,250 |
| FIDELITY BROKERAGE SERVICES, INC. | 2,629 | 4,698 | 5,580 | 15,242 |
| CREDIT SUISSE FIRST BOSTON LLC | 2,244 | 1,771 | 3,768 | 4,421 |
| MORGAN STANLEY & CO., INC. | 4,740 | 2,102 | 17,257 | 4,614 |
| J.P. MORGAN SECURITIES LLC | 4,917 | 5,986 | 7,733 | 31,246 |
| DEUTSCHE BANK SECURITIES INC. | 1,863 | 1,703 | 3,113 | 4,287 |
| UBS SECURITIES LLC | 1,749 | 991 | 2,548 | 2,211 |
| RBC CAPITAL MARKETS, LLC | 1,374 | 1,578 | 3,505 | 5,732 |
| LPL FINANCIAL LLC | 1,323 | 2,400 | 6,633 | 20,083 |
| INVESTMENT MANAGEMENT & RESEARCH | 1,301 | 872 | 4,714 | 5,706 |
| MSI FINANCIAL SERVICES, INC. | 1,078 | 971 | 9,103 | 8,441 |
| PRINCOR FINANCIAL SERVICES CORPORATION | 1,053 | 433 | 4,180 | 4,104 |
| NORTHWESTERN MUTUAL INVESTMENT SERVICES, LLC | 999 | 1,058 | 7,075 | 10,394 |
| H.D. VEST INVESTMENT SECURITIES, INC. | 985 | 860 | 5,091 | 5,108 |
| WACHOVIA CAPITAL MARKETS, LLC | 963 | 1,610 | 1,455 | 3,400 |

***Notes:*** This table shows computations of two groups of professionals at the largest broker-dealer employers. The first group, stock traders, include individuals licensed to trade stocks professionally (holding a Series 7 exam and valid license) who do not hold licenses to act in different market segments or occupations in the investment industry. The second group counts all individuals registered to work in the investment industry directly related to the sale or research on equities products or related activities related to investing in broker-dealers. *IDS Life Insurance merged and was renamed RiverSource Life in 2008. **AG Edwards & Sons was acquired by Wells Fargo Advisors in 2008. ***Lehman Brothers was liquidated in 2008 and its US trading division purchased by Barclays PLC also in 2008. Merril Lynch's employment also counts Banc of America Investment Services and Banc of America Securities which were independent brokers prior to 2009. JP Morgan, Goldman Sachs, Morgan Stanley, and other entities with multiple subsidiaries have employment figures combined and displayed under one firm in the table. No employee counts include office or any personnel not directly involved with the activities described. These were the largest broker-dealer employers of stock traders in 2004.

**Table 3:** Availability of New Technologies by Sector

| | Trading Automation | Fin | Non-Fin |
|---|---|---|---|
| | (1) | (2) | (3) |
| Post RegNMS $\times IT_c^{2004}$ | 0.137*** | 0.097 | 0.016 |
| | (0.034) | (0.061) | (0.106) |
| Year FE | $X$ | $X$ | $X$ |
| County FE | $X$ | $X$ | $X$ |
| # Counties | 107 | 227 | 323 |

***Notes:*** Column (1) estimates difference-in-differences estimates of trading technology availability growth following Reg NMS in counties with different pre-existing IT infrastructure. To benchmark the estimated effect, columns (2) and (3) run the same regression with overall finance patents and non-finance sector patents in the same as the outcomes. Standard errors are clustered at the county level.

**Table 4:** Did Automation Increase Industry Trading Profits?

| | Aggregate Profits | | % Profits Top Brokers |
|---|---|---|---|
| | No Missing Filings | All | |
| | (1) | (2) | (3) |
| Post RegNMS × $IT_c^{2004}$ | 1.009** | 1.445** | 0.044** |
| | (0.439) | (0.716) | (0.021) |
| $t = 2002$—$2014$ | $X$ | $X$ | $X$ |
| Year FE | $X$ | | $X$ |
| County FE | $X$ | $X$ | $X$ |
| Observations | 2,859 | 3,510 | 6,940 |
| # Counties | 288 | 340 | 288 |

***Notes:*** Column (1) estimates a difference-in-differences model with county level aggregate net income from broker-dealers. This sample only includes firms with complete available profit information for all years the firm was operating (it allows for firm entry and exit). Column (2) uses all reporting firms, considering brokers that occasionally appear missing because their net income information was not available. Column (3) has as outcome the share of total local profits at the top broker-dealers (above the median total assets in the county). Standard errors are clustered at the county level.

**Table 5:** Did Automation Increase Firm Trading Profits?

| | Broker-Dealer Profit | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Post RegNMS × $IT_c^{2004}$ | 0.098*** | 0.100*** | 0.053* | 0.058** | | | | |
| | (0.029) | (0.029) | (0.028) | (0.029) | | | | |
| Post RegNMS × $IT_c^{2004}$ | | | | | 0.066*** | 0.066*** | 0.011*** | 0.011*** |
| × Total Assets$_{fct}$ | | | | | (0.014) | (0.014) | (0.002) | (0.002) |
| Year FE | | $X$ | | $X$ | | $X$ | | $X$ |
| Broker-dealer FE | | | $X$ | $X$ | | | $X$ | $X$ |
| $t = 2002$—2014 | $X$ | $X$ | $X$ | $X$ | $X$ | $X$ | $X$ | $X$ |
| County FE | $X$ | $X$ | $X$ | $X$ | $X$ | $X$ | $X$ | $X$ |
| Observations | 25,862 | 23,510 | 25,000 | 25,000 | 25,862 | 23,510 | 25,000 | 25,000 |
| # Counties | 340 | 340 | 333 | 333 | 340 | 340 | 333 | 333 |

***Notes:*** Column (1) regresses firm-level net income on the Reg NMS indicator interacted with the pre-policy local IT level. Column (2) adds year fixed effects to the model. Columns (3) and (4) include broker-dealer fixed effects. Columns (5) through (8) implement the same sequence of difference-in-differences regressions, interacting the variable of interest with the firm's total assets. Using lagged values of total assets or fixed pre-policy shifters changes the magnitude of estimated coefficients, but not the significance. Standard errors are clustered at the county level.

**Table 6:** Impact of Automation on Broker-Dealer Entry & Survival

| # Traders at Firm | 5-year Survival Rate | | | | | | Broker-Dealer Entry |
|---|---|---|---|---|---|---|---|
| | All Firms | < 50 | 50-100 | 100-250 | 250-1000 | 1000+ | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Post RegNMS | 0.016*** | 0.019*** | 0.01 | 0.018 | 0.034** | 0.081*** | $-0.248$** |
| $\times IT_c^{2004}$ | (0.004) | (0.004) | (0.012) | (0.014) | (0.014) | (0.025) | (0.119) |
| Average # Traders | 66 | 8 | 71 | 157 | 454 | 3,219 | |
| # Counties | 311 | 300 | 77 | 64 | 65 | 31 | |
| # Firms | 3,688 | 3,202 | 186 | 146 | 106 | 48 | 3,452 |

***Notes:*** This table compares, from columns (1) through (7), how firm survival rates of different-sized broker dealers changed as a consequence to trading automation. All regressions are of the form $y_{fct} = \alpha_0 + \delta \left( IT_c^{2004} \times \text{Post RegNMS}_t \right) + \gamma X_{fct} + \lambda_t + \mu_c + \varepsilon_{fct}$, where the outcome is a dummy for whether in a given point in time, the firm is still in business in the next 5 years. Post $\text{RegNMS}_t \equiv \mathbb{1}\{t \geq 2007\}$ isan indicator for the post-Reg NMS period, interacted with the pre-policy IT exposure variable, $IT_c^{2004}$. Column (1) runs the specification on all broker dealers and counties. Columns (2)-(6) gradually subsample firms based on employment level, from the smallest to the largest brokers. Column (7) has the outcome the probability that a firm the investment industry in a given year. Standard errors are clustered at the county level.

**Table 7:** Employment *&* Wage of Securities Brokers

| | $Employed_{ict}$ (1) | $Employed_{ict}$ (2) | $Employed_{ict}$ (3) | $\ln(Wage_{ict})$ (4) |
|---|---|---|---|---|
| Post RegNMS × $\widetilde{IT_c^{2004}}$ | −0.322*** | | | |
| | (0.014) | | | |
| Linear trend × $IT_c^{2004}$ | | −0.210*** | | |
| | | (0.011) | | |
| Post RegNMS × $IT_c^{2004}$ | | | −0.401*** | |
| | | | (0.207) | |
| $IT_c^{2004}$ × Post RegNMS$_t$ × Skilled$_i$ | | | | 0.091** |
| | | | | (0.034) |
| Year fixed effects | $X$ | | $X$ | $X$ |
| County fixed effects | $X$ | $X$ | $X$ | $X$ |
| Linear trend | | $X$ | | |
| $t \times \mu_c$ | | | $X$ | |

***Notes:*** Column (1) uses a high-speed internet broadband availability measure as the pre-policy exposure variable. (2) Interacts the IT intensity variable with a linear trend. (3) replicates the baseline model and interacts county fixed effects with a linear trend. (4) runs a triple-DiD specification of wages with differential effects for high and low skilled traders. Standard errors are clustered at the county level.

**Table 8:** Placebo and Robustness Tests

| | $Employed_{ict}$ | $Employed_{ict}$ | $Employed_{ict}$ | $\Delta \ln \left(Emp_c^{2004-2006}\right)$ | $\Delta \ln \left(Emp_c^{2004-2009}\right)$ |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| $\mathbb{1}\left\{t \geq 2004\right\} \times IT_c^{2004}$ | $-0.022$ | $-0.031$ | $-0.041$ | | |
| | (0.025) | (0.025) | (0.033) | | |
| $\Delta IT_c^{2004}$ | | | | $-0.0003$ | $-0.001$ |
| | | | | (0.0006) | (0.001) |
| $t = 2001-2004$ | $X$ | | | | |
| $t = 2001-2005$ | | $X$ | | | |
| $t = 2001-2006$ | | | $X$ | | |
| Year FE | $X$ | $X$ | $X$ | | |
| County FE | $X$ | $X$ | $X$ | | |

***Notes:*** Columns (1)-(3) replicate the baseline model for stock trader employment with a placebo policy intervention and by gradually changing the estimating sample in the pre-Reg NMS years. Columns (4) and (5) test whether the growth rate in local IT infrastructure prior to the 2004 level I use to assign treatment intensity is predictive of future local area stock trader employment. Standard errors are clustered at the county level.

**Table 9:** Great Recession & Online Brokerage Services

| | $Employed_{ict}^{otherfin}$ | $Employed_{ict}$ | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Post RegNMS × $IT_c^{2004}$ | 0.371*** | −0.202*** | −0.038*** | −0.209*** | −0.317*** |
| | (0.016) | (0.011) | (0.017) | (0.015) | (0.015) |
| $\Delta \ln$ (House $\text{Prices}_{ct}$) | | | | −0.046 | |
| | | | | (0.307) | |
| $\text{E*Trade}_{ct}$ | | | | | 0.002 |
| | | | | | (0.004) |
| Omit Big 5 | | X | | | |
| Omit New York | | | X | | |
| Year fixed effects | X | X | X | X | X |
| County fixed effects | X | X | X | X | X |
| Full set of controls | X | X | X | X | X |
| Individual-year observations | 11,904 | 18,496 | 1,617,318 | 22,987 | 9,304 |

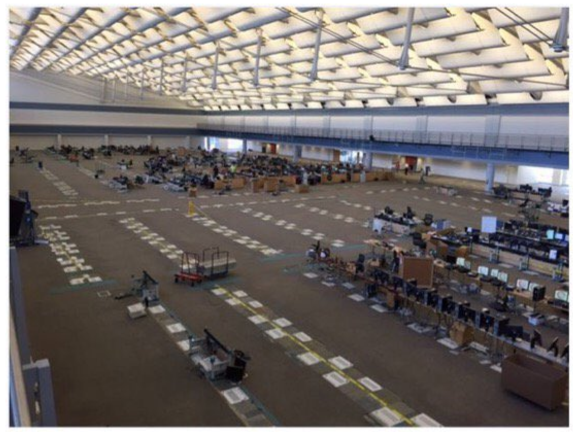
***Notes:*** This table shows estimates of different potential margins the Great Recession and online brokerage services may drive the baseline results for employment. Column (1) compares stock traders to all other finance workers (including outside the investment industry) in the same area. Column (2) drops the Big 5 (Goldman Sachs, Merrill Lynch, Morgan Stanley, JP Morgan, and Lehman Brothers) investment banks. Column (3) excludes workers and firms in New York from the sample. Column (4) controls for local changes in home prices. Column (5) adds as control imputed local number of E*Trade accounts.

# Appendix Figures and Tables

NYSE Trading Floor, 1986

UBS Trading Floor (NJ), 2005


NYSE Trading Floor, 2007



UBS Trading Floor (NJ), 2016

**Figure A.1:** Two Sides of Trading Automation: Exchanges and Broker-Dealers

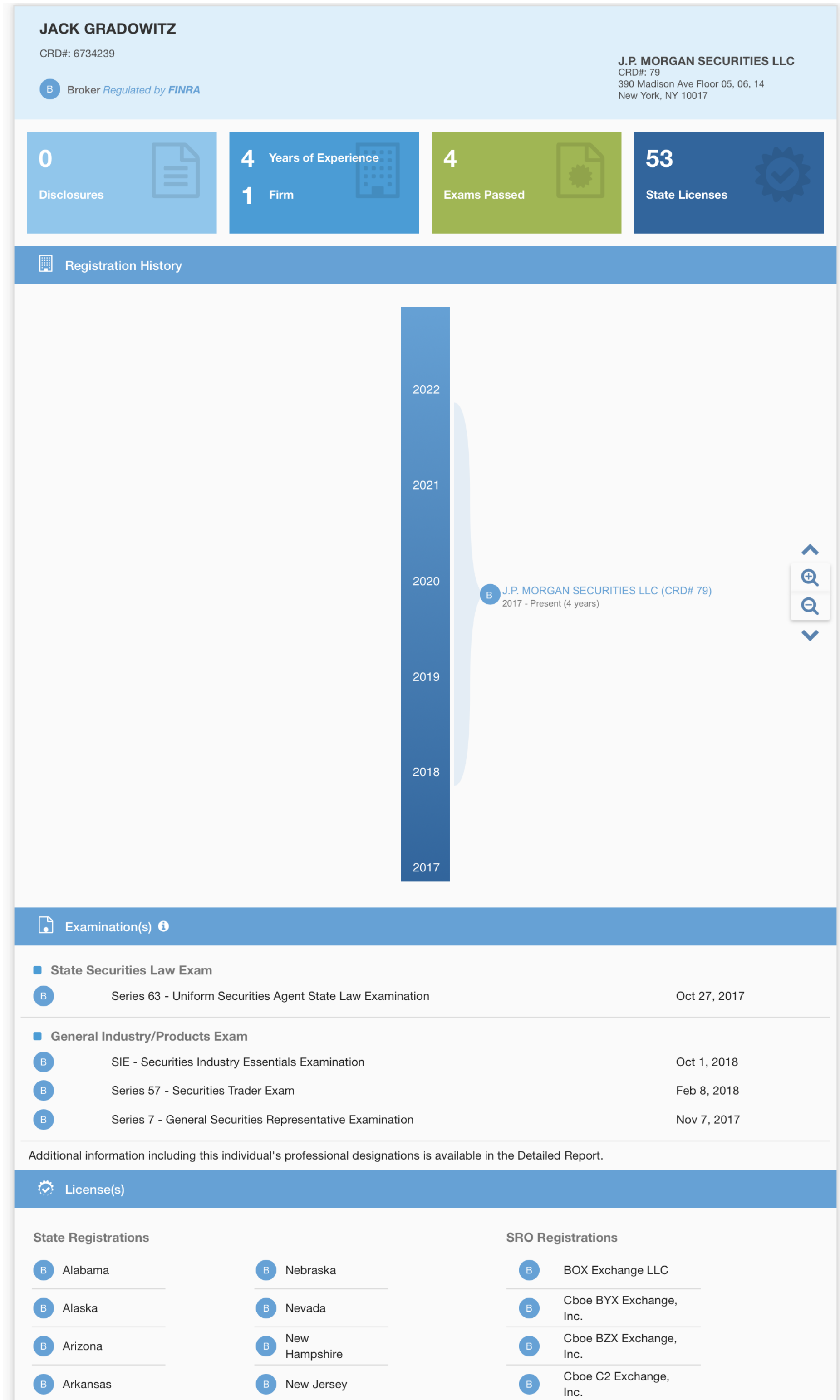



**Figure A.2:** Example of Stockbroker Registration Record from BrokerCheck.com

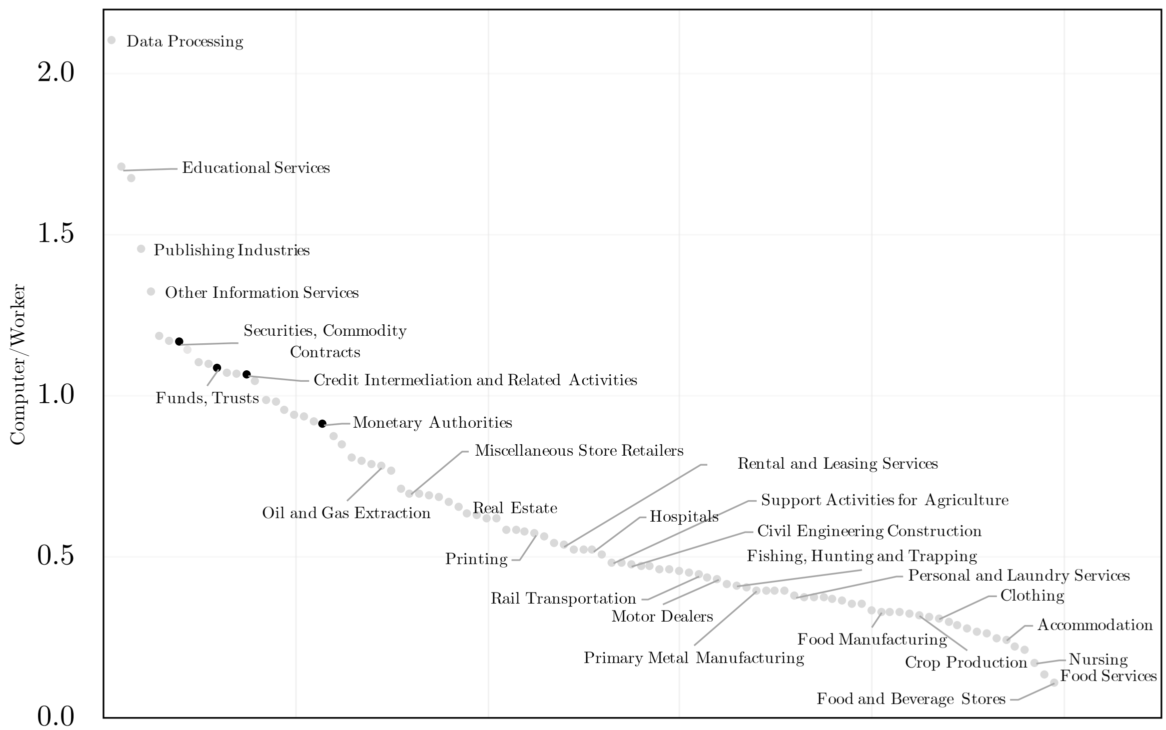
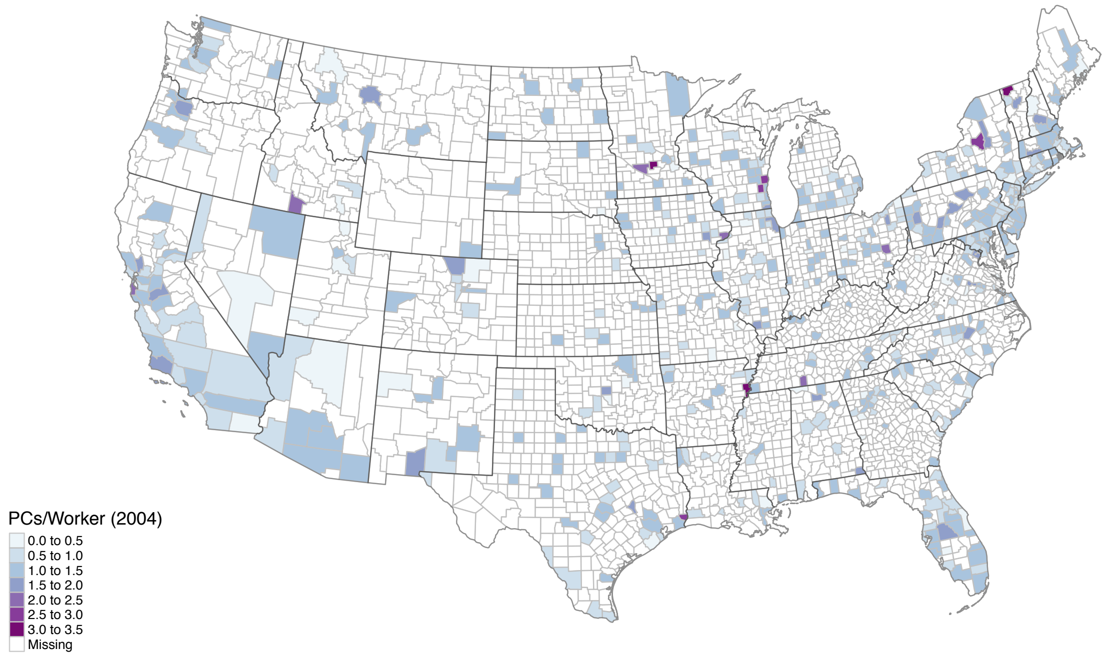



**Figure A.3:** IT Intensity Across Industries in 2004



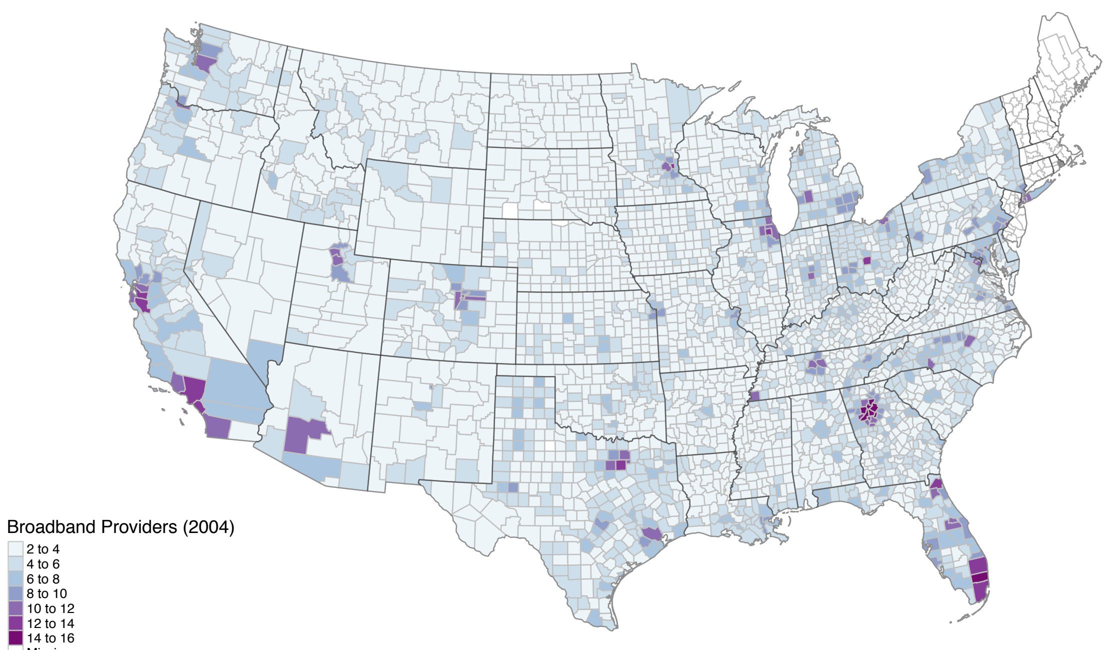




**Figure A.4:** Cross-Sectional Variation: IT Intensity and Broadband Providers

SECURITIES 01 01 1018 COMMISSION
Washington, D.C. 20549

| OMB APPROVAL | |
|---|---|
| OMB Number: | 3235-0511 |
| Expires: | December 31, 1999 |
| Estimated average burden | |
| Hours per response: | 2 |

**ANNUAL AUDITED REPORT**
**FORM X-17A-5**
**PART III**

RECEIVED NOV 27 2001 354

| SEC FILE NUMBER |
|---|
| 8-32706 |

**FACING PAGE**
**Information Required of Brokers and Dealers Pursuant to Section 17 of the Securities Exchange Act of 1934 and Rule 17a-5 Thereunder**

REPORT FOR THE PERIOD BEGINNING 10/01/00 (MM/DD/YY) AND ENDING 09/30/01 (MM/DD/YY)

**A. REGISTRANT IDENTIFICATION**

NAME OF BROKER-DEALER: NOBLE INTERNATIONAL INVESTMENTS, INC.
~~[illegible]~~

| OFFICIAL USE ONLY |
|---|
| FIRM ID. NO. |

ADDRESS OF PRINCIPAL PLACE OF BUSINESS: (Do not use P.O. Box No.)

6501 Congress Avenue, Suite 100
(No. and Street)

Boca Raton (City) FL (State) 33487 (Zip Code)

NAME AND TELEPHONE NUMBER OF PERSON TO CONTACT IN REGARD TO THIS REPORT

DENNIS J. ROSA (561) 994-1191
(Are Code – Telephone No.)

**B. ACCOUNTANT IDENTIFICATION**

INDEPENDENT PUBLIC ACCOUNTANT whose opinion is contained in this Report*

AHEARN, JASCO + COMPANY, P.A.
*(Name – if individual, state last, first, middle name)*

190 SE 19TH AVENUE (Address) POMPANO BEACH (City) Florida (State) 33060 (Zip Code)

**CHECK ONE:**

- ☑ Certified Public Accountant
- ☐ Public Accountant
- ☐ Accountant not resident in United States or any of its possessions.

PROCESSED
MAY 20 2002
THOMSON FINANCIAL

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| |

**Claims for exemption from the requirement that the annual report be covered by the opinion of an independent public accountant must be supported by a statement of facts and circumstances relied on as the basis for the exemption. See Section 240.17a-5(e)(2).*

**Potential persons who are to respond to the collection of information contained in this form are not required to respond unless the form displays a currently valid omb control number.**

SEC 1410 (3-91)

**Figure A.5:** Face of Form X-17A-5 Submitted in Paper Format

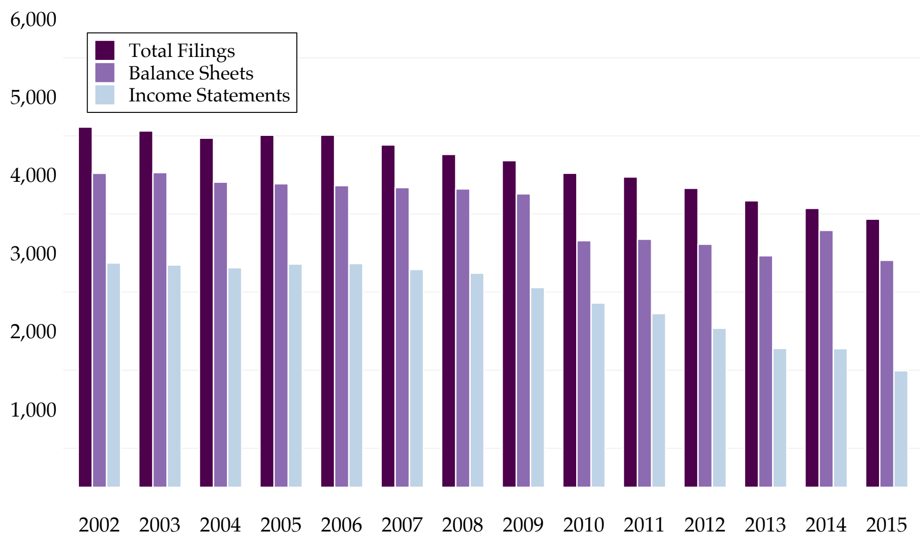


**Figure A.6:** Number of Form X-17A-5 Filed Every Year by Section Available

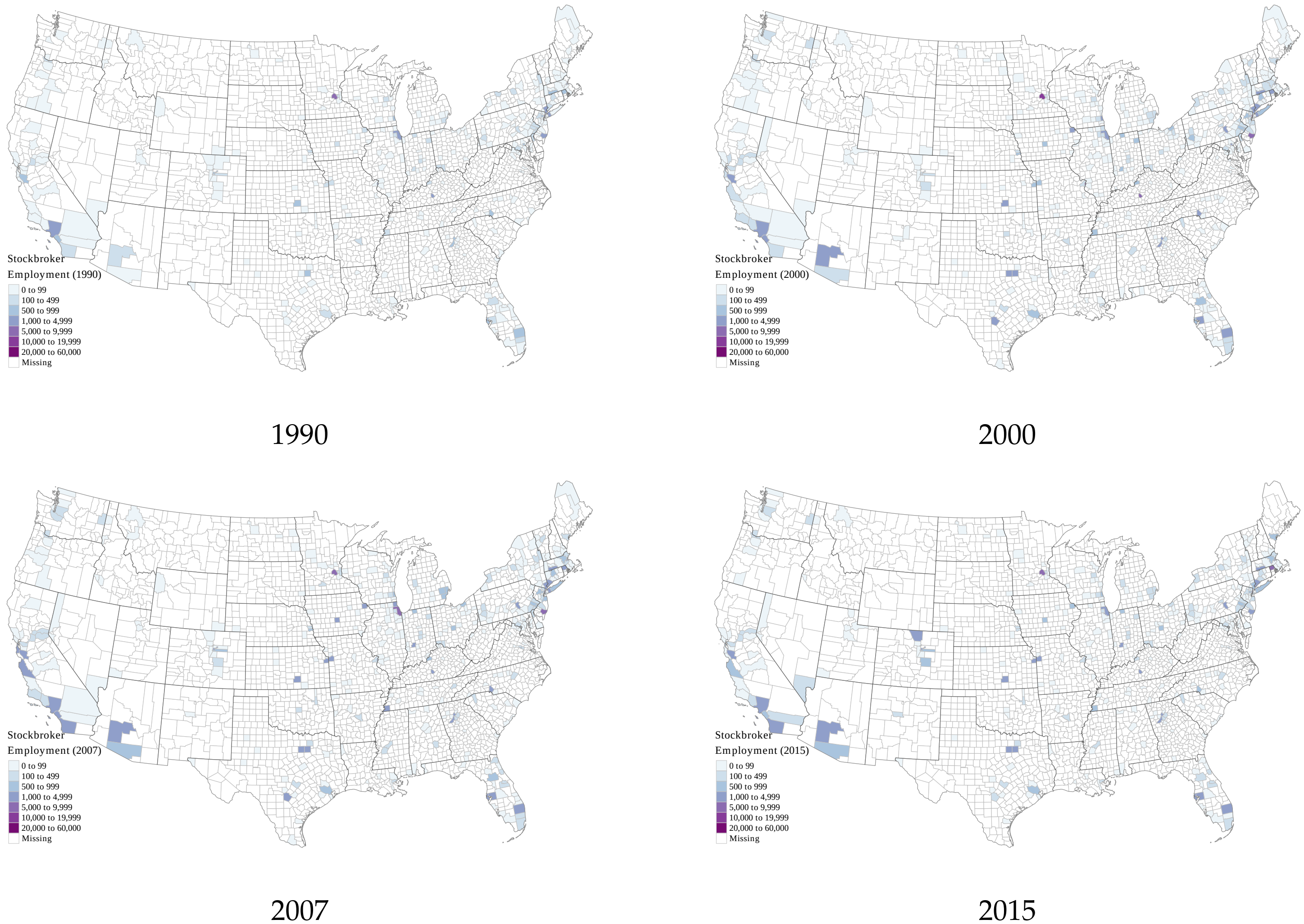


**Figure A.7:** Evolution of Broker-Dealer Employment: US Counties

# Online Appendix

*Financial Regulation and Automation Adoption: Evidence from Stock Trading Firms*

Pedro Tremacoldi-Rossi

# I Broker-Dealer Financial Information

As mandated by Section 17 of the Securities Exchange Act of 1934, Rule 17a-10(a)(1), registered broker-dealers are required to submit X-17A-5 (or Financial and Operational Combined Uniform Single (FOCUS) Reports) forms every year. These documents have statements of financial and operation condition, among other information such as net capital requirements (in compliance with Rule 15c3-1). Contrary to other financial data readily available to the public, including from forms 10-K and 8-K, until 2017, these forms are not centrally index by the SEC.

**Extraction steps.** To access and extract broker-dealer financial information, I develop and implement the following general steps:

1. Obtain all entity names associated with a given FINRA CRD code
2. Obtain all Central Index Key (CIK) codes for each of the entity names
3. Find under which CIK forms 13F and X-17A-5 are filed
4. Find SEC Document Control Numbers (DCNs) of every filing
5. Retrieve paper document based on DCN

**An example.** To illustrate the multiple steps necessary to connect financial information across different SEC and FINRA databases in practice, consider Goldman Sachs. FINRA's database lists four different entity names under Goldman Sachs' CRD code 361: i) **Goldman Sachs & Co. LLC**, ii) **Goldman Sachs Asset Management**, iii) **Goldman Sachs & Co.**, and iv) **Marcus Invest Offering of Goldman Sachs & Co. LLC**.


**Figure I.1:** Goldman Sachs Listed Names at BrokerCheck.com

Each of these entities may file under different Central Index Key (CIK) codes. Often times, the same nominal entity has several CIKs for filing specific forms. For example, under the **Goldman Sachs & Co. LLC** name, there are three CIKS: 42352, 734700, and 769993. Neither 734700 nor 769993 file X-17A-5 forms, but 769993 files 13F-NTs – a 13F notice required when the entity's holdings are reported by another manager, usually the parent or holding company. These forms list **Goldman Sachs Group Inc** as the entity filing 13Fs including the assets of **Goldman Sachs & Co. LLC**. While I do not use holdings data in this paper, this procedure would match the broker-dealer entity **Goldman Sachs & Co. LLC** to its correct reporting 13F entity, **Goldman Sachs Group Inc**.Finally, note that the parent company may include holdings from other subsidiaries or their own.

UNITED STATES SECURITIES AND EXCHANGE COMMISSION
Washington, D.C. 20549
FORM 13F

FORM 13F COVER PAGE

Report for the Calendar Year or Quarter Ended: 06-30-2021
Check here if Amendment ☐ Amendment Number:
This Amendment (Check only one.): ☐ is a restatement.
☐ adds new holdings entries.

**Institutional Investment Manager Filing this Report:**

| | |
|---|---|
| Name: | GOLDMAN SACHS & CO. LLC |
| Address: | 200 WEST STREET |
| | NEW YORK, NY 10282 |
| Form 13F File Number: | 028-00687 |

**The institutional investment manager filing this report and the person by whom it is signed hereby represent that the person signing the report is authorized to submit it, that all information contained herein is true, correct and cor**

Person Signing this Report on Behalf of Reporting Manager:

| | |
|---|---|
| Name: | Terry Mosher |
| Title: | Vice President |
| Phone: | 972-368-6370 |

**Signature, Place, and Date of Signing:**

| | | |
|---|---|---|
| /s/Terry Mosher | Dallas, TX | 08-13-2021 |
| [Signature] | [City, State] | [Date] |

**Report Type (Check only one.):**

☐ 13F HOLDINGS REPORT. (Check here if all holdings of this reporting manager are reported in this report.)
☒ 13F NOTICE. (Check here if no holdings reported are in this report, and all holdings are reported by other reporting manager(s).)
☐ 13F COMBINATION REPORT. (Check here if a portion of the holdings for this reporting manager are reported in this report and a portion are reported by other reporting manager(s).)

**List of Other Managers Reporting for this Manager:**
**[If there are no entries in this list, omit this section.]**

| Form 13F File Number | Name |
|---|---|
| 028-04981 | GOLDMAN SACHS GROUP INC |

**Figure I.2:** Example of Goldman Sachs & Co. LLC 13-NT

Finally, **Goldman Sachs & Co. LLC** files X-17A-5 forms under CIK 42352. With the company's correct CIK code, I access the its history of filings at the EDGAR Entity Landing Page, which provides filing statistics for all documents submitted beginning in 2001. The SEC associates a unique document ID to each filing received — known as film number or Document Control Number (DCN). The final step of retrieving forms X-17A-5 involves extracting each film number from Goldman's records at the Entity Landing Page, then directly download the paper copy from SEC's archive repository. I iterate the same steps for each registered broker-dealer in the US, resulting in over 80,000 unique X-17A-5 forms since 2001.

CONDERA SECURITIES, LLC
STATEMENTS OF FINANCIAL CONDITION

| | December 31, 2011 | December 31, 2010 |
|---|---|---|
| ASSETS | | |
| CURRENT ASSETS | | |
| Cash and cash equivalents | $ 188,300 | $ 175,610 |
| Fees receivable, net | 28,134 | 248,451 |
| TOTAL CURRENT ASSETS | 216,434 | 424,061 |
| PROPERTY AND EQUIPMENT | | |
| Furniture and fixtures | 32,104 | 32,104 |
| Equipment | 1,856 | 1,856 |
| Computers | 26,950 | 26,950 |
| Software | 25,082 | 25,082 |
| | 85,992 | 85,992 |
| Less: accumulated depreciation | 78,150 | 71,456 |
| NET PROPERTY AND EQUIPMENT | 7,842 | 14,536 |
| TOTAL ASSETS | $ 224,276 | $ 438,597 |

**FAR HILLS GROUP, LLC**

**STATEMENT OF FINANCIAL CONDITION**

| December 31, 2015 | |
|---|---|
| **ASSETS** | |
| **Cash and cash equivalents** | $ 1,711,889 |
| **Fees receivable** | 4,429,042 |
| **Property and equipment, net** | 293,053 |
| **Restricted cash, security deposit** | 207,048 |
| **Other assets** | 287,498 |
| | $ 6,928,530 |

**Figure I.3:** Broker-Dealer Balance Sheet Examples, Assets

**Parsing.** X-17A-5 forms are PDF scans of the paper document. Prior to 2008, most files do not have digitized text, which first requires the use of an optical character recognition (OCR) engine to extract raw text. These are detection algorithms designed to extract text from images and can be fine-tuned to convert images of statement of cash flows tables, for example, into standard text strings.

A second issue is related to the variety of reporting standards adopted by broker-dealers. Although required balance sheet lines are generally uniform, different companies provide various disaggregation levels, details, or names to each accounting line. The same variation in reporting standards involves income statements, explanatory notes, and leverage calculation. To homogenize these information and extract reported values, I use the standard version of SEC's entry system to report the information in X-17A-5 forms and allocate a broker-dealer's balance sheet layout to this standardized mold.

**Table I.1:** Standardizing Broker-Dealer Balance Sheet, Assets

| ASSETS |
|---|
| 1. Cash |
| 2. Cash segregated in compliance with federal and other regulations |
| 3. Receivable from brokers or dealers and clearing organizations |
| 3-A. Failed to deliver |
| 3-B. Securities borrowed |
| 3-C. Omnibus accounts |
| 3-D. Clearing organizations |
| 3-E Clearing organizations (deposits) |
| 4. Receivables from customers |
| 4-A. Securities accounts |
| 4-B. Commodity accounts |
| 4-C. Allowance for doubtful accounts |
| 4-D Commissions receivable |
| 5. Receivables from non-customers |
| 5-A. Cash and fully secured accounts |
| 5-B. Partly secured and unsecured accounts |
| 5-C Registered representatives |
| 6. Securities purchased under agreements to resell |
| 7. Securities and spot commodities owned, at market value |
| 7-A. Bankers acceptances, certificates of deposit and commercial paper |
| 7-B. U.S. and Canadian government obligations |
| 7-C. State and municipal government obligations |
| 7-D. Corporate obligations |
| 7-E. Stocks and warrants |
| 7-F. Options |
| 7-G. Arbitrage |
| 7-H. Other securities |
| 7-I. Sport commodities |
| 8. Securities owned not readily marketable |
| 9. Other investments not readily marketable |
| 10. Securities borrowed, at market value |
| 11. Secured demand notes |
| 12. Memberships in exchanges |
| 13. Investment in and receivables from affiliates, subsidiaries and associated partnerships |
| 14. Property, furniture, equipment, leasehold improvements and rights under lease agreements |
| 15. Other Assets |
| 16. Prepaid Expenses |
| 17. TOTAL ASSETS |

Often times, broker-dealers report only part of the exhaustive list of balance sheet variables. Alternatively, some of standard lines may not apply to a particular firm — e.g., market value of options when the firm does not trade derivatives. To guarantee the accuracy of the extracted data, I manually check 750 randomly chosen forms and impose consistency constraints, such as total assets being equal to total liabilities and no asset component being larger than the total asset value.