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Innovation and Economic Volatility: Facts and Theory

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An abstract of
A thesis submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
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in Economics

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Abstract

Innovation and Economic Volatility: Facts and Theory

By Yanbing Min

The pioneer work, Comin and Mulani (2007, JME), contributes the diverging trends between microeconomic and macroeconomic level volatility to the arrival of general purpose technology found by the market leaders. This paper documents that the patent count as a measure of innovation can significantly account for the increase in firm volatility and the decline in aggregate level volatility, replacing the effect of general purpose technology in the recent literature. Here, I document the data collection, construction and regression results. Also, a benchmark general equilibrium model is proposed using industry equilibrium as in Melitz (2003).

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"*Innovation is the key to economic growth and job creation, and increasingly important to American competitiveness in the global economy. Three-quarters of all U.S. economic growth, and three quarters of the U.S. productivity advantage over other OECD nations, is directly attributable to innovation, and wages in innovation-intensive industries have grown more than twice as fast as other wages in recent decades.*" (A famous politician)

1 Introduction

Comin and Mulani (2007, JME) contributes the diverging trends between microeconomics and macroeconomic level volatility to the arrival of general purpose technology by market leaders. Chun, Kim and Morck (2011, REStat) confirms one side of the story: exposing to general purpose technology leads higher microeconomic or firm level volatility. Chun et al (2011) uses IT intensity as general purpose to capture firm dynamics. These findings motivate this paper and we find patent as a measure of innovation is more general approach.

This paper intends to build a general equilibrium model to quantitatively explain the diverging trends. Wang and Wen (2013 and 2010) are among the first ones addressing this issue in a DSGE model. They find financial development contributes to this interesting fact. They first propose a unified model by incorporating Kiyotaki and Moore (1997)'s financial friction in to a real business cycle model with heterogenous agents. However, technology plays no role in their theoretic model. What is underlying the diverging volatility between micro-level and macro-level still unknown to us. In this paper, I would like to confront this question using both empirical evidence and general equilibrium modeling.

The purpose of this paper is twofold. First, I construct a comprehensive dataset using the raw NBER patent dataset, Compustat from Standard & Poor's and macroeconomic data from Federal Reserve Economic Data (FRED), on which I construct the level of innovation, industry level volatility and firm level volatility. I then present evidence based on post 1975 time series and panel data to suggest that the diverging trend does exist in the data. Second, I develop a general equilibrium model of industry level equilibrium. A particular goal is to provide a unified approach to understand the diverging trends.

One limitation of this paper is that it does try to disentangle the effect of the innovation and the financial market on the diverging trends. There is a large literature on how a better financial structure expedites the firm innovation (Hsu, Tian and Xu (2014, JFE) among others). It is possible that financial market plays a fundamental role in forming the diverging trends. This could be a future topic.

Using patent as proxies of technological innovations (as in Hsu (2009) among others), we can empirically test the conjecture on how innovation affect both firm level and aggregate level volatility. As Simon Kuznet (1962) documented, one of the main obstacles to investigate the role innovation in the economy is the measure of innovation. Although we may have lots of potential substitutes for innovation measure including the number of scientific journal articles (Price, 1963) and scientists and engineers (Gort, 1969), most commonly used technological statistics are patent and R&D due to their availability and economic and financial importance.

Between patent and R&D, patent has its special advantage in addressing problems in both firm level and aggregate level data. First, Griliches (1990) docoments the co-movement between R&D and patents' over the business cycle. Results from patents can mostly contain the effects of R&D. Second, patents embody the innovation output, which actually affects the real economy. And Lev (2001) finds patents are most actively traded intangible assets in intellectual property markets. Third and most importantly, Griliches (1990) also reports that firms tend to publicize new innovation very soon after R&D efforts. Although R&D is available, it is always under-reported.

Other related literature. When technology innovation arrives, due to its inherent uncertainty and market participants's heterogeneous perceptions, it brings about volatility in the economy. Recent literature highlights the role of innovation in increasing idiosyncratic stock return volatility. Shiller (2000) finds stock returns are more volatile than underlying fundamentals in the periods of technological change. Greenwood and Jovanovic (1999) finds IT revolution caused stock market sharp decline and bounce back during 1970s and 1980s. Campbell et al. (2001) also claims Dot-com revolution brought about by information technology largely contribute to the market volatility. Mazzucato (2002) verifies Campbell et al. (2001)'s conjecture and document the high stock return volatility when innovation arrives by looking at automobiles industry. Classic literature, like Kortum (1997) and Dinopoulos and Thompson (1998), already find a positive relationship between R&D and firm level accounting data.

The following of this paper is organized as follows. Section 2 documents the sources of the data used in the paper, data construction and summary statistics. Section 3 illustrates the relation among the data. Section 4 summarizes the regression results. Section 5 proposed a setting of a benchmark model. The last section concludes.

2 Data

2.1 Data Sources

In order to examine micro-level volatility, I gather annual financial data from COMPUSTAT including firm from 1950s to 2015. Annual level GDP is obtained from FRED. In order to compare the effect of patent with IT, which is the proxy for general purpose technology, I compute IT intensity data following Chun, Kim and Morck (2011, Restat). I obtained the original data from Bureau of Economic Analysis (BEA) using Fixed Assets and Consumer Durable Goods in the link requested from BEA[1]. The original Firm-level patent data is downloaded from NBER Patent Project website, which is originally created by Hall, Jaffe, and Trajtenberg (2001).

2.2 Data Construction

To measure volatility, I first follow literature using 10-year rolling window standard deviation of firm sales and then take annual average of this time series data. Also, I use Chen and Zha (2014, wp)'s measure of dispersion between financially constrained and un-constrained firms. Finally, in order to get robust results of the effect of innovation on firm volatility, following current literature, I calculated each firm's volatility within certain decades and constructed a firm-decade panel data.

- Time-series measure: As in Comin and Mulani (2007) and other literature where they calculate firm-level volatility as the ten-year rolling window standard deviation of firm annual sales:

$$\hat{\sigma}_t(X) = \sqrt{\frac{\sum_{j=0}^{j=9}(X_{it-j} - \hat{\mu}_t)}{10}} \tag{1}$$

- Time-series measure[2]: Chen and Zha (2014)'s dispersion: They run cross sectional regression for each year and use the estimation of b_t as a measure of dispersion between financially constrained and un-constrained firms.

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[1] It's a old link requested from BEA http://www.bea.gov/national/FA2004/Details/Index.htm

[2] This measure is not reported in this paper. It is an alternative of the firm level volatility and serves the purpose of robust test.

$$\log\mathrm{KP}_{it} = a_t + b_t d_{it} + \varepsilon_{it} \tag{2}$$

- Firm-Decade panel: standard deviation of annual sales within the decade and take the average across firms.

Under time-series measures of volatility, when we test the effect of patent count together with IT intensity, IT intensity is either not significant or being replaced by patent[3]. Since firm-level general purpose technology measure is not available, we do not know if it could play a role in addressing the diverging trends between microeconomic and aggregate level volatility.

To measure innovation, we follow existing innovation literature, mainly in the fields of corporate finance, asset pricing and industry organization, to adjust the measure of innovation in order to address the truncation problems in NBER patent database. The truncation problem arises as the application-grant lag inherent in patent issue procedure. And we only observe granted patent in the database. In fact, as we approach the end of the data period, we see a dramatic drop in patent applications. In the estimation of Hall, Jaffe, and Trajtenberg (2001) among others, the application-grant lag is about 2 years on average. Many patent applications filled around 2005 are still under review. Following Hall, Jaffe, and Trajtenberg (2001), we correct the truncation by estimating the empirical application-grant lag distribution for patent filed and granted between 1995 and 2000. Define w_t as the empirical application-grant distribution. It's the percentage of patent is granted t years after application. Then the truncation adjusted patent count is

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[3] Results are not reported here in this paper since this paper focuses solely on addressing the diverging trends. Also, lack of data points in the time-series regression could raise certain concerns on the validity of the regression model.

$$\text{Patent}_{adj} = \frac{\text{Patent}_{raw}}{\sum_{\tau=0}^{2006-t} w_\tau}, \quad 2001 \leq t \ \leq 2006 \tag{3}$$

The distribution of the pooled sample is right-skewed with 75th percentile of the distribution at zero.

2.3 Summary Statistics

Table 1 summarizes the volatility of sales on average patents growth rate and employment for 15,966 COMPUSTAT firms. We get similar results when including lagged sales as control variable in Table 2. The sample only includes firms with identifiable records of number of patents. If we can't distinguish if the firm has zero patents or missing data, they are not included in the regressions. Volatility is calculated as the standard deviation of annual sales from non-overlapping decades from 1975 through 2005.

[**Place Table 1 about here**]

[**Place Table 2 about here**]

3 Empirical Findings

Stylized Fact 1. The decline in aggregate volatility coincides with the increase in firm-level volatility.

Figure 1 shows the background of the following findings. It plots the starkest example diverging trends among micro- and macro- level data. Starting from around 1970, firm-level volatility and aggregate-level volatility moves in the opposite directions. Pearson's correlation is -0.7 and significant at 1 percent level. Dashed line plots the aggregate-volatility measured as the 10-year standard deviation of GDP annual growth rate. Dot-dashed line plots the 10-year rolling window standard deviation of firm sales. This firm-level and aggregate-level evidence suggests that is tradeoff between stability in the macro level and dispersion among micro level. More concretely, aggregate-level and firm-level volatility in COMPUSTAT U.S. publicly listed firms are strongly negatively correlated.

[Place Figure 1 about here]

Stylized Fact 2. Industry-level production volatility declines with patent growth rate in the cross section.

The declining trend of industry volatility is one of the stylized facts. Comin and Mulani (2007, JME) firsts contributes this trend to technology innovation. They find general purpose technology is the driving force under this phenomenon. Chun, Kim and Morck (2011, REStat) confirms their findings. And these two literature are the starting motivation of this paper. I find, however, when using patent count as a measure of innovation, its effect wins over general purpose technology. The relation between patent and industry-level volatility is illustrated in Figure 2, which plots the (log) level of volatility, measured as the standard deviation of annual sales over non-overlapping decades from 1975 through 2005, against the average (log) level of patent growth rate of the decade [4]. The graph also shows the linear regression line together with the 95-percent confidence interval band produced using robust standard error.

[Place Figure 2 about here]

In Figure 2, manufacturing firm-level data are averaged to get 2-digit SIC industry level. The robust OLS regression indicates that 1 percent increase in the patent

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[4] It's $log(1+g)$, where g is the growth rate. Adding 1 is to avoid the zeros when taking logarithm. Later in this paper, I use the same expression.

growth rate would induce about -2 reduce in the industry-level volatility. The results are significant at 5 percent significance level. Industry-level volatility and innovation are significantly negatively correlated.

Stylized Fact 3. There exists positive association between firm-level volatility and innovation.

As shown in Figure 3, firm-level volatility and innovation are positively correlated. The relation between firm-level volatility and innovation is illustrated in Figure 3, which plots the (log) level of volatility, measured as the standard deviation of annual sales over non-overlapping decades from 1975 through 2005, against the average (log) level of patent growth rate of the decade. The graph also shows the linear regression line together with the 95-percent confidence interval band produced using robust standard error.

In Figure 3, manufacturing firm-level data are matched to patent data. The robust OLS regression indicates that 1 percent increase in the patent growth rate would induce about -0.083 reduce in the industry-level volatility. The results are significant at 1 percent significance level. Firm-level volatility and innovation are significantly positively correlated.

[**Place Figure 3 about here**]

Stylized Fact 4. The positive association between firm-level volatility and innovation takes place at all levels of financial development.

The relation between firm-level volatility and innovation holds at different levels of financial constraints. It differentiates this paper from Wang and Wen (2013, wp), in which they contribute the diverging trends among macro- and micro- level to different degrees of financial development. One parameter in the borrowing limit constraint as in Kiyotaki and Moore (1997) plays the key role in their paper. This is illustrated in Figure 4 and Figure 5, where we split the level of financial constraints into two categories. In literature on customarily proxy for financial constraint as documented in Campello, Graham and Harvey (2009, NBER), characteristics like small firm size, non-dividend paying status, or poor credit ratings are used to distinguish the financially constrained and un-constrained. Following Chen and Zha (2014, wp), we categorize firm with annual sales less than 75 percentiles as financial constrained and the rest as un-constrained. Figure 4 and Figure 5 show that the increase of volatility with the innovation measure, growth rate of patent. The increase is not sensitive to the financial constrained condition. That is, controlling by financial constraint condition, there is still a strong positive association between volatility and innovation.

This empirical observation motivates an important feature of my paper of innovation that differentiates it from models of financial constraints: Unlike the latter, my evidence and proposed model framework introduce a new channel through firm's market power after obtaining innovation.

A second important empirical observation is that, consistent with Davis, et al. (2006), the decline in aggregate volatility in the U.S. has been driven by a increase in firm-level volatility. That is, the results coincide the idea that the aggregate-level volatility is by aggregation of increasingly more volatile but rarely correlated firms in their market performance.

[Place Figure 4 about here]

[Place Figure 5 about here]

Stylized Fact 5. Extensive margin and intensive margin are correlated for firm innovation.

Figure 6 plots the number of firms with at least one patent in hundreds and patents per firm across the data period. One series drops around year 2000 may be due to the truncation problem in the patent data. With this decline to the end of the data period, the two series still show significant correlation. The Pearson's correlation is 0.8 and significant at 1 percent significant level. Given this empirical correlation, I do not distinguish between innovation by entrant and by incumbent.

[Place Figure 6 about here]

4 Regressions

I formally summarize my findings in Table 3, Table 4 and Table 5. More innovative firms exhibit larger dispersion in size. The decrease in aggregate dispersion coincides with the increase in firm-level dispersion. Firm-level evidence suggests that there is no trade-off between larger dispersion and innovation. More concretely, innovation and dispersion in US firm-level data are strongly positively correlated. This is illustrated in Table 3, which shows the coefficients from regressions of dispersion of sales on average patents granted and employment for 15,966 Compustat firms. We get similar results when including lagged sales as control variable in Table 4. The sample only includes firms with identifiable records of number of patents. If we can't distinguish if the firm has zero patents or missing data, they are not included in the regressions. Volatility is calculated from non-overlapping decades from 1975 through 2005. Innovation and employment are positively and negatively correlated with firm-level size dispersion, respectively. The positive correlation between innovation and size dispersion remains strong even if we include firm-fixed effects to consider within-firm variation only. In other words, firms becoming more innovative also become more dispersed in size across years.

[Place Table 3 about here]

[Place Table 4 about here]

Table 5 summarizes the association of industry-level volatility and innovation. The first two columns show the coefficients from a regression of (log) volatility on patent growth rate, excluding and including fixed effects. The coefficients are statistically significant at the 1 percent level. The third and fourth columns show the corresponding results when volatility is regressed on the (log) number of employee. As anticipated, the relation is negative; and when fixed effects are included, the estimated elasticity is still both statistically and economically significant. Finally the last two columns show the regression results when both variables are included in the regression. Volatility is strongly and negatively associated with patent growth rate.

[Place Table 5 about here]

These stylized facts serve as the empirical motivation of building a model addressing the diverging economic volatility using innovation.

5 General Equilibrium Model

5.1 Setup

In this section, I write a static general equilibrium model. Parameters' behavior responses at only one point in time. In each industry, there is a continuum number of firms of certain mass. I model three sectors in this economy, households, consumption-good producers and innovators. Later, we could model innovator's behavior recursively and expand the number of industries up to certain amount. This model is built on Melitz (2003).

Households' Utility Maximization Problem: The representative household supply labor inelastically each period to consumption-good producers (p) and innovators (e) at wage w_t in a competitive labor market. She consumes the composite consumption C_t in each period from each industry i to maximize her utility function,

$$\max_{\{C_t\}} \sum_t \beta^t \log\,(C_t). \tag{4}$$

The parameter β is the discount factor. The composite consumption C_t is in the constant elasticity of substitution (CES) form:

$$C_t = \left[\sum_i \eta_i C_{i,t}^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{5}$$

where θ captures the elasticity of substitution among industries. The parameter η_i captures the degree of heterogeneity among industries. Industry-consumption goods are the weighted sum over different varieties in their own industry:

$$C_{i,t} = \int_0^{M_{i,t}} \rho_{i,t} c_{i,t}(\omega)\ d\ \omega, \tag{6}$$

where the parameter $\rho_{i,t}$ captures the heterogeneity among different varieties ω of measure $M_{i,t}$, or or benefit from product variety, in the industry i. The representative households maximize utility function equation (4) subject to the budget constraint,

$$\sum_i \left[\int_{M_{i,t}} p_{i,t}(\omega) c_{i,t}(\omega) d\omega + s_{i,t+1} V_{i,t+1} \frac{M_{i,t+1}}{1-\delta} + s^e_{i,t+1} V^e_{i,t} \right] \tag{7}$$
$$\leq w_t L + \sum_i \left[s_{i,t}(V_{i,t} + \pi_{i,t}) M_{i,t} + s^e_{i,t}(V^e_{i,t} + \pi^e_{i,t}) \right]$$

Households' Choice over Industries: Once households decide how much resources to allocation to consume goods in different industries, the demand curve can be derived by solving the following cost minimization problem:

$$\min_{C_{i,t}} \int_i P_{i,t} C_{i,t} di, \tag{8}$$

subject to

$$\left[\sum_i \eta_i C_{i,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \geq C_t. \tag{9}$$

Households' Preference over Varieties: In each industry i at period t, there is a mass of varieties $M_{i,t}$ for consumer to choose from. In order to capture households' preference over varieties, I apply Feenstra (2003)'s transcendental logarithmic (translog) utility. Loualiche (2013, dissertation) extends Feenstra (2003) to a continuum of varieties. I reproduce Loualiche (2013) here to make the paper self-contained.

$$\log(E) = \log(\hat{U}) + a_0 + \int_0^{M_{i,t}} a(\omega) \log(p(\omega))\, d\omega + \int \int_{[0,M_{i,t}]^2} \gamma_{\omega\omega'} \log(p(\omega)) \log(p(\omega'))\, d\omega d\omega'. \tag{10}$$

To ensure homogeneity of degree one, we assume

$$\int_{M_{i,t}} \gamma_{\omega\omega'}\, d\omega = 0, \quad \int_{M_{i,t}} a(\omega) = 1. \tag{11}$$

Consumption-Good Producers: This model only has producers at firm level.

One variety is one firm or one producer.

$$\max \ \pi_{i,t}(\omega) = p_{i,t}(\omega)c_{i,t}(\omega) - w_{i,t}l^p_{i,t}(\omega), \tag{12}$$

subject to

$$c_{i,t}(\omega) \leq z_{i,t}(\omega)l^p_{i,t}(\omega), \quad z_{i,t}(\omega) \equiv z \sim G(z), \tag{13}$$

$$G(z) = 1 - \left(\frac{z_{\min}}{z}\right)^{\frac{k}{M_{i,t}}}, \quad z_{\min} = \text{argmin } z_{i,t}(\omega), \quad \omega \in [0, M_{i,t}] \text{ and } \frac{k}{M_{i,t}} \geq 2, \tag{14}$$

$$\frac{\partial \ \text{log}c_{i,t}(\omega)}{\partial \ \text{log}p_{i,t}(\omega)} = -\xi_{i,t}(\omega)(M_{i,t}), \tag{15}$$

where $\xi_{i,t}(\omega)$ is the price elasticity of demand, which is derived from translog preference.

Innovators: Innovators use single input to produce new varieties and sell them to the households. They maximize profit as follows:

$$\max_{\{M^e_{i,t}\}} \ \pi^e_{i,t} = M^e_{i,t}V^e_{i,t} - w_t L^e_{i,t}, \tag{16}$$

subject to

$$b\left(\frac{M^e_{i,t}}{M_{i,t}}\right)^a \leq L^e_{i,t}, \tag{17}$$

$$V^e_{i,t} = \max_{\{M^e_{i,t}\}} \ \mathrm{E}_t\left[\sum_{\tau=0}^{\infty} \frac{\Lambda_{t+\tau}}{\Lambda_t}(M^e_{i,t+\tau}V_{i,t+\tau} - w_{t+\tau}L^e_{i,t+\tau})\right]. \tag{18}$$

Firm Mass Dynamics:

$$M_{i,t+1} = (1-\delta)(M_{i,t} + M^e_{i,t} - M(\mathbb{1}_{\pi_{i,t}(\omega)<0})). \tag{19}$$

5.2 Equilibrium

The equilibrium consists of a set of prices $\{p_{i,t}(\omega),\ w_t,\ V_{i,t},\ V^e_{i,t}\}$ and a set of allocations $\{c_{i,t}(\omega),\ C_{i,t}(\omega),\ C_t,\ L^e_{i,t},\ L^p_{i,t},\ M_{i,t},\ s_{i,t+1},\ s_{i,t+1}\}$ such that:

[1] Given a set of prices $\{p_{i,t}(\omega),\ w_t,\ V_{i,t},\ V^e_{i,t}\}$, households solve utility maximization problem under a set of allocations $\{c_{i,t}(\omega),\ C_{i,t}(\omega),\ C_t,\ L^e_{i,t},\ L^p_{i,t},\ M_{i,t},\ s_{i,t+1},\ s_{i,t+1}\}$;

[2] Given a set of prices $\{p_{i,t}(\omega),\ w_t,\ V_{i,t},\ V^e_{i,t}\}$, firms solve profit maximization problem under a set of allocations $\{c_{i,t}(\omega),\ L^e_{i,t},\ L^p_{i,t},\ M_{i,t}\}$;

[3] Labor markets clear, good markets clear and asset markets clear.

5.3 Analysis

The section attempts to explain the relation among cross-sectional industry-level volatility, firm-level volatility and innovation. At I only consider the static part of the model.

Increasing Firm-level Volatility: Firm's output is from consumption-good producers' problem in Equation (12). Let $\lambda^{(1)}_{i,t}(\omega)$ and $\lambda^{(2)}_{i,t}(\omega)$ be the two Lagrangian multipliers of the two constraints in the firm's problem. The first order condition reads:

$$l^p_{i,t}(\omega): \quad w_{i,t} = z_{i,t}(\omega)\lambda^{(1)}_{i,t}(\omega), \tag{20}$$

$$c_{i,t}(\omega): \quad p_{i,t}(\omega) = \lambda^{(1)}_{i,t}(\omega) + \frac{\lambda^{(2)}_{i,t}(\omega)}{c_{i,t}(\omega)}, \tag{21}$$

$$p_{i,t}(\omega): \quad c_{i,t}(\omega) = \frac{\xi_{i,t}(\omega)\lambda^{(2)}_{i,t}(\omega)}{p_{i,t}(\omega)}. \tag{22}$$

Then, we can solve for a firm's output as:

$$c_{i,t}(\omega) = \lambda_{i,t}^{(2)}(\omega)\frac{z_{i,t}(\omega)(1+\xi_{i,t}(\omega))}{w_{i,t}}. \tag{23}$$

Loualiche (2013) solves for the price elasticity of demand as a function of the mass of firm varieties in a industry.

$$\xi(\omega) = 1 + \gamma M_{i,t}, \tag{24}$$

where γ is a positive parameter.

Each firm draws productivity individually and independently. Each variety ω has its own productivity $z_{it}(\omega)$. Thus, the volatility lies in the distribution of productivity and the Lagrangian multiplier is independently of the mass of variety. Then, the cross-sectional firm-level volatility is

$$\begin{aligned} \mathrm{var}(c_{i,t}(\omega)) &= \left[\lambda_{i,t}^{(2)}(\omega)\frac{(1+\xi_{i,t}(\omega))}{w_{i,t}}\right]^2 \ \mathrm{var}(z_{i,t}(\omega)) & (25) \\ &= \left[\lambda_{i,t}^{(2)}(\omega)\frac{(1+\xi_{i,t}(\omega))}{w_{i,t}}\right]^2 \ \frac{\frac{k}{M_{i,t}}z_{min}^2}{(\frac{k}{M_{i,t}}-2)(\frac{k}{M_{i,t}}-1)^2}. & (26) \end{aligned}$$

When the economy has more varieties, firm-level volatility increases. To simplify, I use M to represent $M_{i,t}$.

$$\begin{aligned} \frac{\partial \mathrm{var}(c_{i,t}(\omega))}{\partial M_{i,t}} = \left(\frac{\lambda_{i,t}^{(2)}(\omega)}{w_{i,t}}\right)^2 & \left(\frac{2\left(2+\gamma M\right)kz\gamma}{M\left(\frac{k}{M}-2\right)\left(\frac{k}{M}-1\right)^2} - \frac{\left(2+\gamma M\right)^2 kz}{M^2\left(\frac{k}{M}-2\right)\left(\frac{k}{M}-1\right)^2}\right. & (27) \\ & \left. + \frac{\left(2+\gamma M\right)^2 k^2 z}{M^3\left(\frac{k}{M}-2\right)^2\left(\frac{k}{M}-1\right)^2} + \frac{2\left(2+\gamma M\right)^2 k^2 z}{M^3\left(\frac{k}{M}-2\right)\left(\frac{k}{M}-1\right)^3}\right). \end{aligned}$$

The derivative $\frac{\partial \mathrm{var}(c_{i,t}(\omega))}{\partial M_{i,t}} \geq 0$ as long as the mass of varieties $M_{i,t}$ is large enough.

We can see it from the first two terms in the second parentheses in Equation (27).

$$\frac{2\left(2+\gamma M\right)kz\gamma}{M\left(\frac{k}{M}-2\right)\left(\frac{k}{M}-1\right)^2}-\frac{\left(2+\gamma M\right)^2kz}{M^2\left(\frac{k}{M}-2\right)\left(\frac{k}{M}-1\right)^2}=\frac{(2+\gamma M)kz}{M(\frac{k}{M}-2)(\frac{k}{M}-1)^2}(\gamma-\frac{2}{M}) \quad (28)$$

Decreasing Industry-level Volatility: At this stage, I only consider two industries. Solve for the households' cost minimization problem as in Equation (8). The isoelastic demand curve is

$$C_{i,t}=\eta_i^\theta\left(\frac{P_{i,t}}{P_t}\right)^{-\theta}C_t. \quad (29)$$

Assuming symmetric firm with the same price, the industry level price is firm-level price ($p_{i,t}(\omega)$) divided by benefit from varieties (ρ_i) as in Loualiche (2013). Thus, the industry-level demand/output is

$$C_{i,t}=\eta_i^\theta\left(\frac{w_t(1+\gamma M)}{z_{it}(\omega)\rho_i(2+\gamma M)P_t}\right)^{-\theta}C_t, \quad (30)$$

since $p_{i,t}(\omega)=\frac{\xi_{i,t}(\omega)}{1+\xi_{i,t}(\omega)}\lambda_{i,t}^{(1)}(\omega)$ from firm's profit maximization problem.

$$\frac{\partial C_{i,t}}{\partial M}\leq 0. \quad (31)$$

Suppose the distribution of mass of firm across different industries follows uniform distribution, I solve the variance from

$$\mathrm{var}(C_{i,t})=\mathrm{E}(C_{i,t}^2)-\mathrm{E}(C_{i,t})^2. \quad (32)$$

And we can solve for $\frac{\partial \mathrm{var}(C_{i,t})}{\partial M}\leq 0$.

[Place Figure 7 about here]

6 Conclusions

The U.S. economy has experienced diverging trends in volatility at the macroeconomic and the firm level. Under this background, the industry level and the firm level volatility also move in opposite directions. This paper explores if the firm innovation contributes to the diverging phenomenon and contributes to the literature empirically and theoretically. Importantly, the upward trend in the firm volatility has interesting implications for the less volatile macroeconomy. Since the scarcity of innovation and the increasing difficulties in inventing new technologies, the economy staggers. We have reasons to conclude that the two trends are related. In the data, we see that the firm innovation significantly contributes to firm volatility and industry volatility. To explain the divergence, I build a industry general equilibrium model. In my model, when firms innovate more, the firm level volatility increase while the industry level volatility decreases. Two forces contributes to the divergence. First, firms enter in the economy with different endowments and the arrival of innovation is rare. When one firm successfully innovates, it obtains extensive market power. The other firms start to mimic the market leader, which brings about different adjustment cost in firms beginning with different endowments, and consequently increasing volatility among firms during this process. Second, at the industry level, the co-movement among firms reduces the volatility.

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Figure 1: Diverging Trends between Micro and Macro Level Data

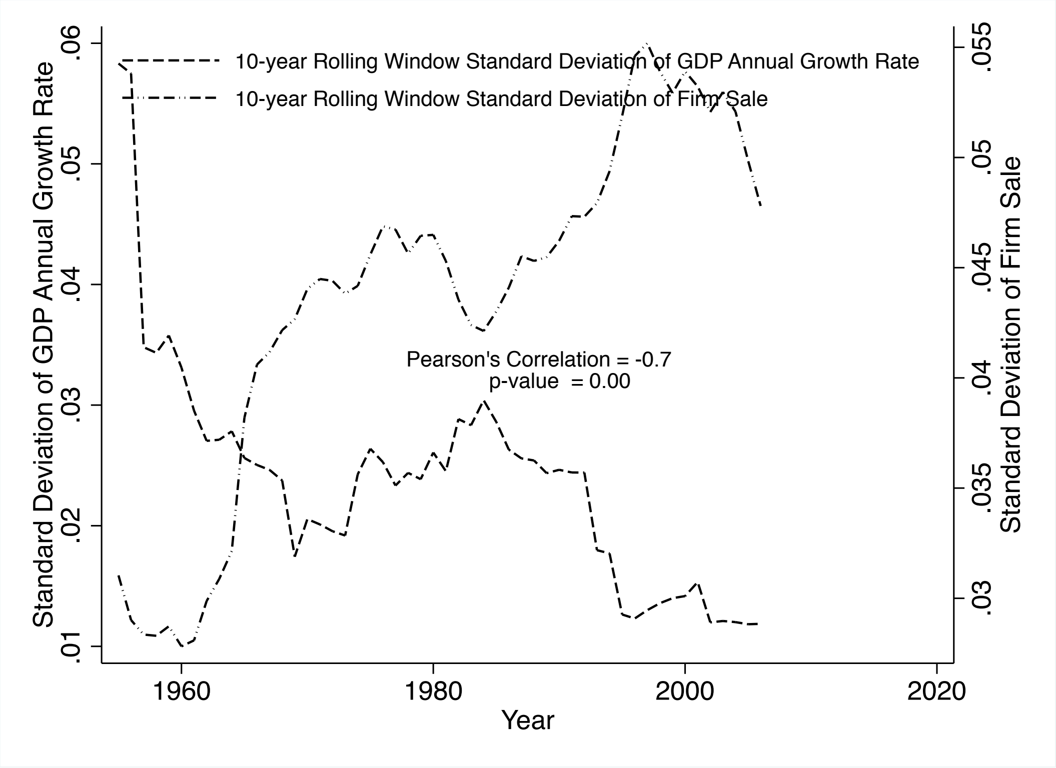

Figure 2: Industry-Level Volatility and Patent Growth Rate

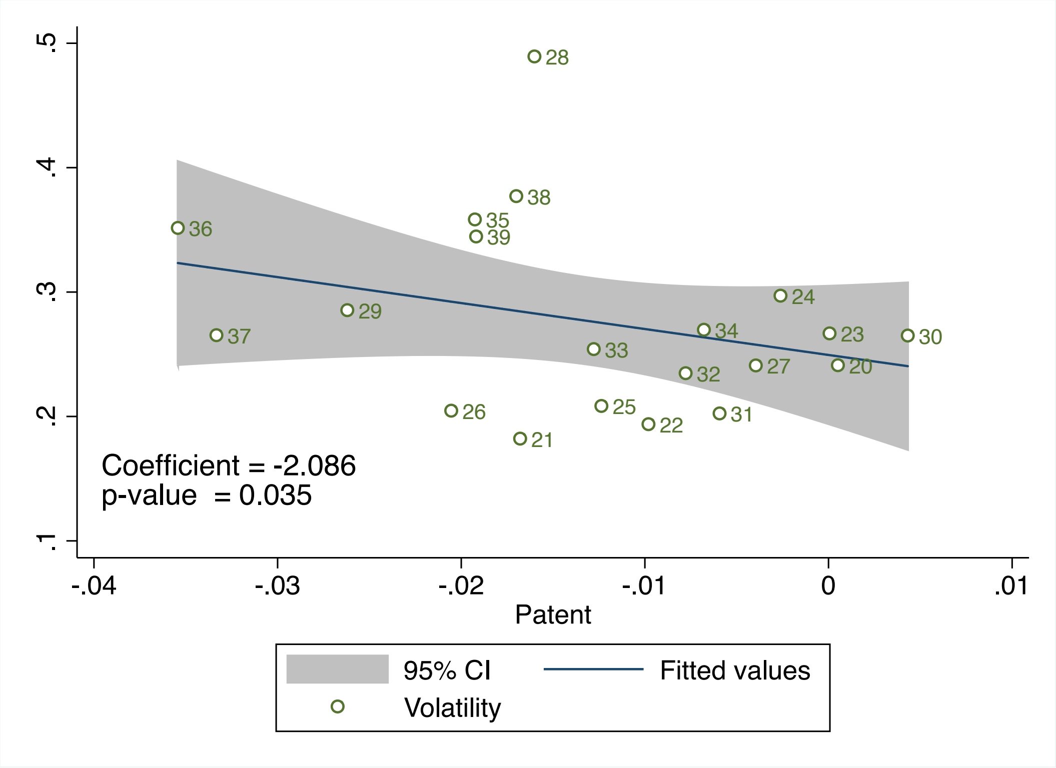

Figure 3: Firm-Level Volatility and Patent Growth Rate with Pooled Sample

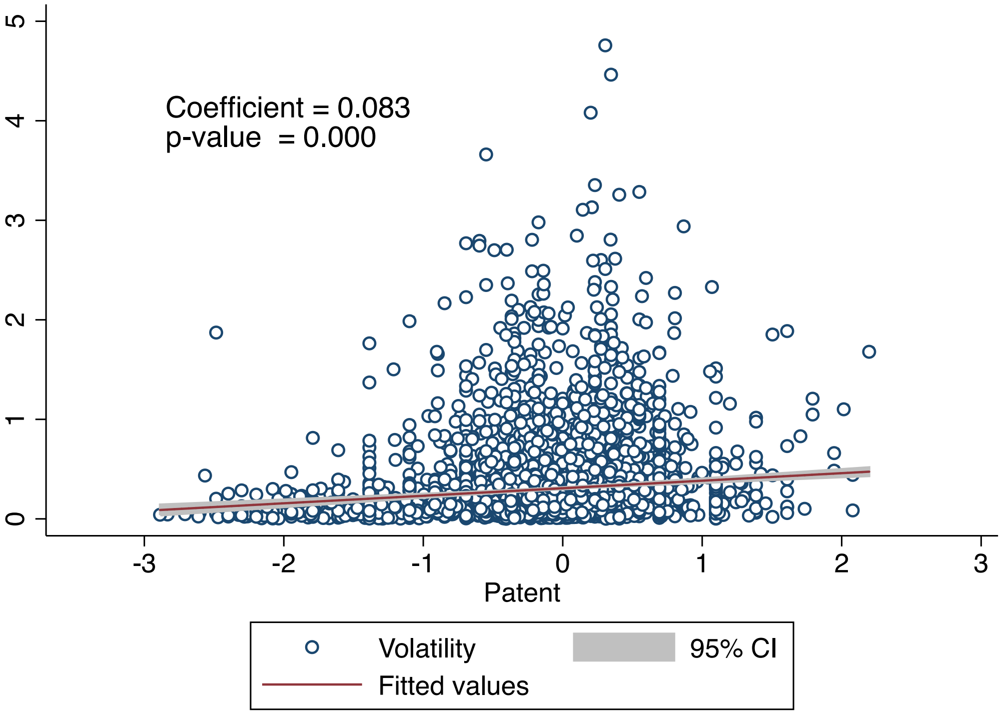

Figure 4: Firm-Level Volatility and Patent Growth Rate with Unconstrained Firms

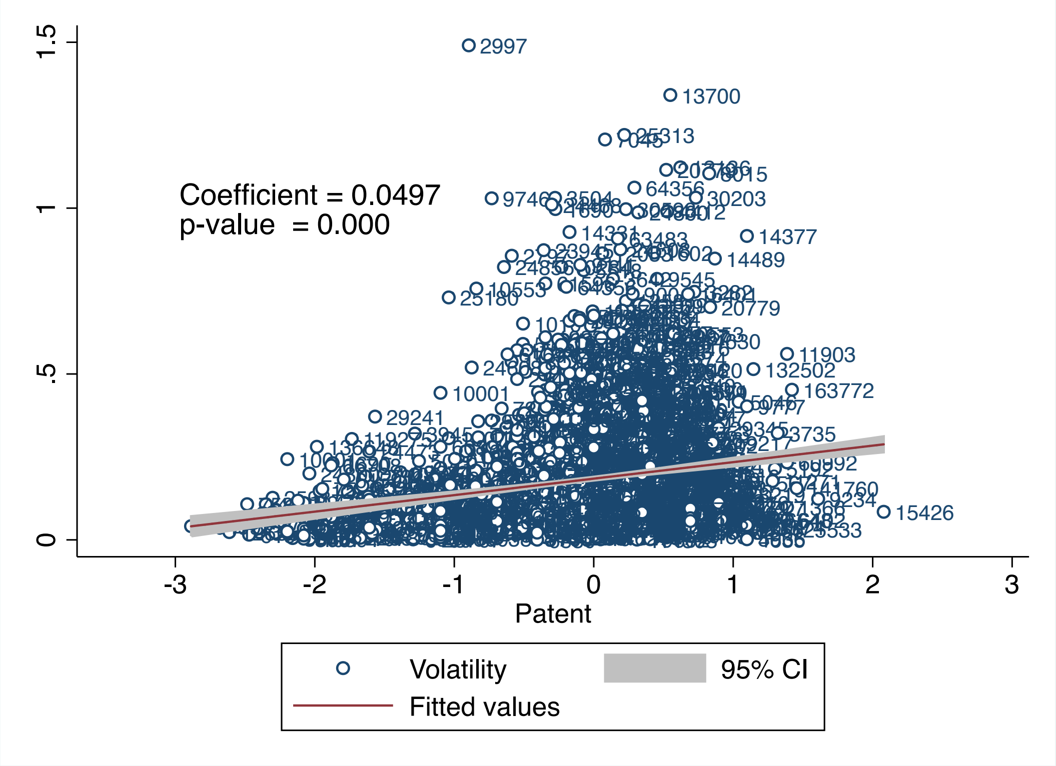

Figure 5: Firm-Level Volatility and Patent Growth Rate with Constrained Firms

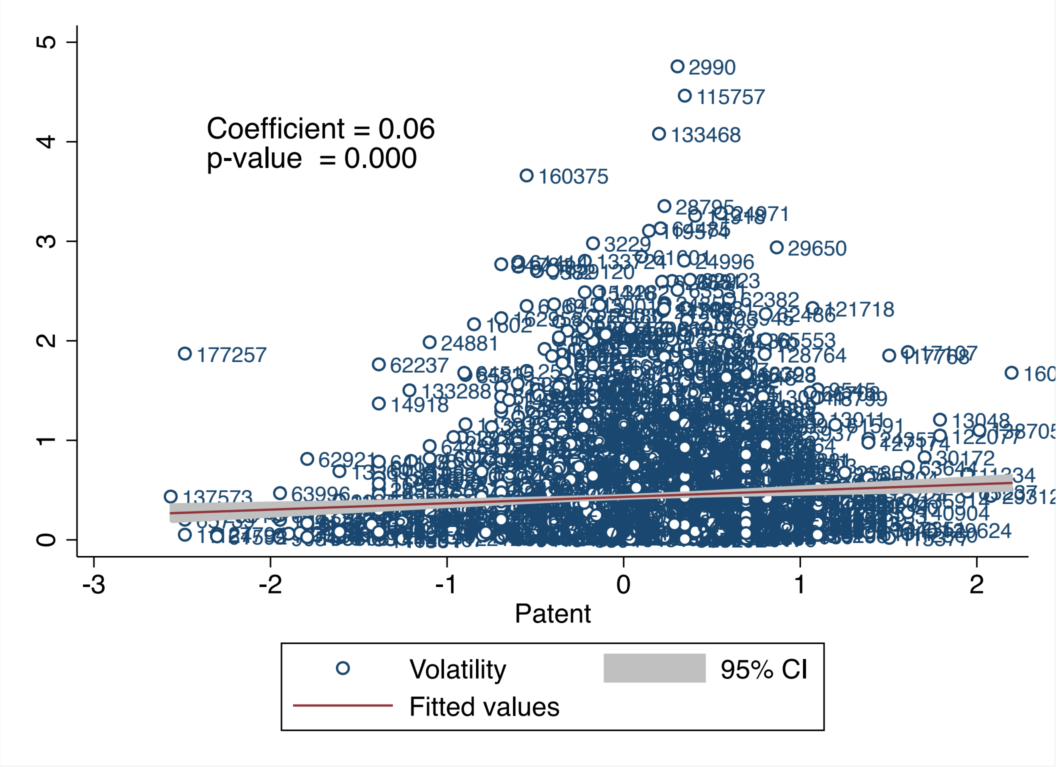

Figure 6: Firm-Level Volatility and Patent Growth Rate with Constrained Firms

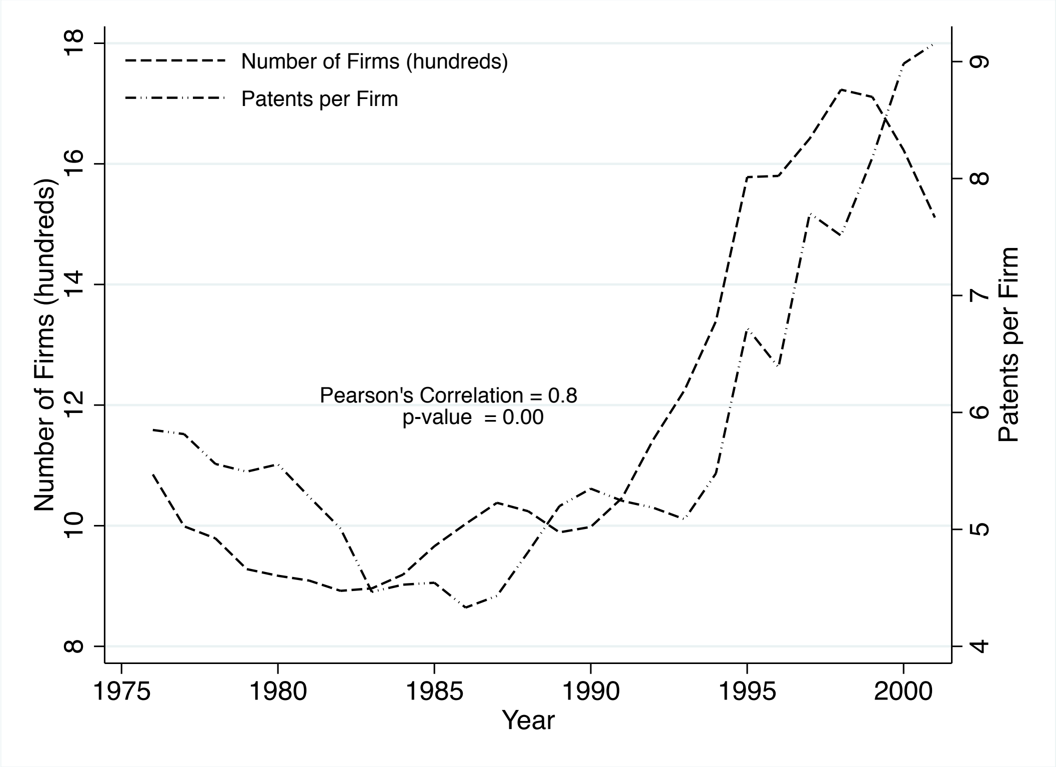

Figure 7: Volatility's Derivative w.r.t. Varieties

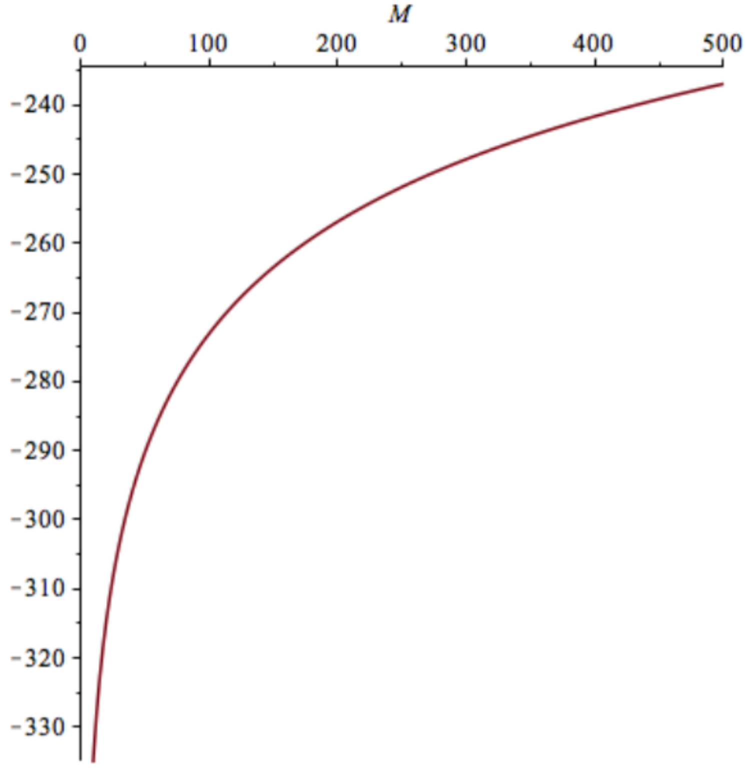

Table 1: Summary Statistics - Full Sample

	N	mean	sd	min	max
Volatility	55,363	0.35	0.46	0.00	6.64
Patent	55,363	-0.01	0.19	-2.89	2.30
Empolyee	55,363	-0.73	2.28	-6.91	7.47

Notes: All variables are in logs. The Volatility is the dependent variable measured as the standard deviation of annual sales over non-overlapping decades from 1975 to 2005.

Table 2: Summary Statistics - Sample with Lagged Sales

	N	mean	sd	min	max
Volatility	37,496	0.31	0.42	0	5.73
Patent	37,496	-0.01	0.19	-2.89	1.7
Employee	35,785	-0.54	2.32	-6.91	7.47
Lagged Sales	37,496	0.83	4.37	-0.01	215.73

Notes: All variables are in logs. The Volatility is the dependent variable measured as the standard deviation of annual sales over non-overlapping decades from 1975 to 2005. Lagged Sales is the control variables added in the following regression. It is the sales in logs and divided by 1,000.

Table 3: Firm-Level Patents and Volatility

	Dependent Variable: Standard Deviation of Size			
Patents	0.092***	0.083***	0.043***	0.062***
	(0.011)	(0.010)	(0.010)	(0.010)
Employee			-0.071***	-0.118***
			(0.001)	(0.003)
Constant	0.353***	0.353***	0.303***	0.269***
	(0.002)	(0.002)	(0.002)	(0.002)
Firm Fixed Effects	No	Yes	No	Yes
Decade Fixed Effects	Yes	Yes	Yes	Yes
Observations	55,363	55,363	51,775	51,775
R-squared	0.010	0.724	0.197	0.753

Notes: All variables are in logs. The dependent variable is measured as the standard deviation of annual sales over non-overlapping decades from 1975 to 2005. The regressors are computed at their mean values over the decade. Clustered standard errors in parentheses. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 4: Firm-Level Patents and Volatility with Lagged Sales

	Dependent Variable: Standard Deviation of Size			
Patents	0.046***	0.046***	0.020*	0.036***
	(0.012)	(0.011)	(0.011)	(0.011)
Employees			-0.066***	-0.098***
			(0.001)	(0.003)
Constant	0.319***	0.317***	0.273***	0.261***
	(0.002)	(0.002)	(0.002)	(0.003)
Lagged Sales	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	Yes	No	Yes
Decade Fixed Effects	Yes	Yes	Yes	Yes
Observations	37,496	37,496	35,785	35,785
R-squared	0.007	0.392	0.127	0.431

Notes: All variables are in logs. The dependent variable is measured as the standard deviation of annual sales over non-overlapping decades from 1975 to 2005. The regressors are computed at their mean values over the decade. Clustered standard errors in parentheses. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 5: Industry-Level Patents and Volatility

	Dependent Variable: Standard Deviation of Size			
Patent	-2.654**	-2.119***	-2.731***	-2.115***
	(1.094)	(0.678)	(1.027)	(0.681)
Employee			-0.129***	0.006
			(0.020)	(0.027)
Constant	2.167***	2.169***	2.130***	2.179***
	(0.028)	(0.016)	(0.027)	(0.019)
Firm Fixed Effects	No	Yes	No	Yes
Decade Fixed Effects	Yes	Yes	Yes	Yes
Observations	497	497	495	495
R-squared	0.010	0.665	0.089	0.648

Notes: All variables are in logs. The dependent variable is measured as the standard deviation of annual sales over non-overlapping decades from 1975 to 2005. The regressors are computed at their mean values over the decade. Clustered standard errors in parentheses. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.