Losses from Trade: The Case of China's Pro-innovation Subsidy Program

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Abstract

The largest subsidy program for industrial innovation in China (InnoCom) appears to raise the quantity of patents but lowers patent quality. Importantly, gains from patent trade - emphasized in the existing literature - appears to be more than offset by trade-enabled losses in welfare. Patent trade creates two sources of efficiency loss: (a) firms not eligible for subsidy may produce low-quality patterns which they sell to subsidy-eligible firms, and (b) firms that are subsidy-eligible but low-value users of patents may buy them from high-value but subsidy-ineligible users. The estimation of our structural model suggests that the overall welfare effect of the program is negative, and the trade-enabled welfare losses are substantially greater than the direct loss from subsidy-eligible firms producing low-quality patents.

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1 Introduction

As innovation may entail a positive spillover, and the temporary monopoly afforded by patent protection may not be sufficient to correct the market failure, most countries choose to provide a subsidy to innovation, sometimes in the form of a reduction in corporate tax rates. The largest pro-innovation subsidy program, InnoCom, offers a reduction in the corporate income tax by 40 percent (or a reduction in the corporate income rate from 25 percent to 15 percent) to eligible firms in eight designated industries. An important feature of the program is that subsidy-competing firms can use patents bought from other innovators to qualify for the subsidy, including those from outside the designated industries. Since the subsidy aims to promote commercializable innovation, it appears to be beneficial that the same subsidy program can inspire many more firms to pursue innovation including those not directly applying for the subsidy.

That trade improves welfare and that a positive externality can be corrected by a subsidy are two old and powerful ideas in economics. Applying them to intellectual property rights (IPRs), the existing literature has highlighted welfare improvement from trade in patent. In particular, when initial innovators and best users of a patent are not the same entities, patent trade can eliminate the initial mis-allocation of innovations (see Akcigit et al. (2016); Serrano (2010)). Separately, recognizing that offering a temporary monopoly through patent protection is not insufficient, most countries also provide a direct subsidy to innovation including tax deduction for patentable innovations.[1] In this paper, we study possible welfare losses enabled by patent trade in such innovation subsidy programs. We use data from the largest pro-innovation program in China, the InnoCom program, to quantify these effects.

[1]A type of subsidy with growing popularity is called "patent box", which is a term for the application of a lower corporate tax rate to the income derived from the ownership of patents. This instrument has been introduced by more than 50 countries since 2000. This tool is different with the widely used instrument: R&D tax credit. The latter one is an ex-ante incentive targeting a firm's innovation input, whereas the first one is ex-post and will only be used when innovation has been patented.

When subsidizing patents, it is common to allow for acquired patents through patent trade to also qualify for subsidy as those developed in house. For example, the patent box policy in more than 10 countries do not distinguished purchased versus self-developed patents for the purpose of subsidy. A rational may be that the social value of a patent is in its commercialization, not innovation itself. If the same subsidy program can inspire more firms to engage in comercializable innovation, including firms that do not directly compete for subsidy, it is considered a desirable outcome of the program. The Chinese InnoCom program also allow subsidy-competing firms to use purchased patents the same way as self-developed patents.

We show that such feature may introduce additional welfare loss since bureaucrats usually can only count patents but cannot differentiate quality. Importantly, allowing patents acquired through patent trade may amplify the welfare loss by spreading subsidy-induced production of low quality patents from subsidy-competing firms to a bigger set of firms.

It is generally hard for government officials to discern the true quality of an innovation. Subsidy programs targeting ex-post innovation outcome (i.e. patents) in practice are often conditional on some quantity indicators such as the number of patents a firm holds.[2] While subsidies based on bean counting can cause subsidy-eligible firms to produce low-quality patents, trade in patents may exacerbate the welfare loss by creating two more channels of efficiency losses. The first is production of low-quality patents by firms/individuals not eligible for pro-innovation subsidy, as long as they expect to be able to sell patents to subsidy-eligible firms. The second channel is an additional mis-allocation when a high social-value user of a patent that is not eligible for subsidy sells the patent to a subsidy-eligible but low social value user. We show in our sample that the trade-enabled welfare losses is very

[2]For instance, since the patent box subsidizes revenues generated from patents, it may encourage firms to patent solely in order to receive subsidy. As Klemens (2016) points out, "The patent box gives new life to zombie patents".

significant, and sometimes is even greater than the direct loss from low-quality patents produced by subsidy-eligible firms.

Our empirical assessment focuses on the Chinese InnoCom program, by far the biggest pro-innovation program in the country in terms of budgetary outlay.[3] Established in 2008, the program is meant to encourage production of intellectual property rights (IPRs) in eight designated industries that the government regards as "industries of future".[4] IPRs generally include patents and software copyrights in these industries. The bureaucrats use a grading system to decide which firms to subsidize. The more IPRs a firm holds (up to 6 IPRs), the greater the likelihood of receiving a subsidy. Once the IPR count reaches 6, additional IPRs would not increase the grade any more. Note that the bureaucrat does not distinguish between self-developed IPRs and externally purchased IPRs.[5] Hence the policy gives a strong incentive for firms to increase their IPRs up to 6, either through self-development or purchasing from others.

We are able to obtain several unique firm-level and patent-level data sets associated with the InnoCom program in a large city and will focus our empirical work on that city. We separate all IPRs (patents/software) holders into two groups: subsidy-competing-enterprises (SCEs), which satisfy the basic eligibility of the InnoCom program (such as having a sufficiently high ratio of R&D expenditure to total expenditure and within 8 designated industries), and non-competing-entities (NCEs), which are firms, individual innovators, or other institutions that are not eligible for the program (such as with a low ratio of R&D/total

[3]Figure 1 plots the central government's annual budgets of various Chinese pro-innovation policies in 2015. As we can see, the budget of InnoCom program dominates other pro-innovation programs.

[4]These eight industries are the pharmaceutical manufacture (CSIC 27), the special equipment manufacture (CSIC 36), the transportation equipment manufacture (CSIC 37), the communication equipment & computer manufacture (CSIC 40), the precision instrument manufacture (CSIC 41), computer service (CSIC 61), software service (CSIC 62) and environmental protection industry (CSIC 80).

[5]This policy design may be based on the bureaucrat's understanding that patent trade could solve an initial mis-match between the initial inventors and the best users of the patents.

expenditure or outside the eight designated industries.).[6] For each type of enterprise, we construct their IPRs portfolio and merge it with their financial information (conditional on they are indeed firms). Within the IPRs portfolio, we know more information about patents than software copyrights, such as whether patents have been traded (including both buyer and seller information) or renewed. Since this data limit, we mainly focus on patents through out the paper.

We document a few salient facts from the data. First, we find that although patent counts increases faster, the quality of patents declines since 2008. We measure patent quality in three different ways: renewal decision by firms holding the patents, forward citation count, and the change in labor productivity when a firm holds one more patent. All three proxies yield the same result: a decline in patent quality after the InnoCom.

Second, an analysis of the proprietary data on bureaucrats' scores on InnoCom applicant firms reveals that the bureaucrats count the number of IPRs but cannot tell the difference in the quality of the innovations. That is, while a higher number of patents pushes up the firm score, a proxy for patent quality by their ex post citation count or ex post renewal rate does not predict a higher score. In addition, whether a patent is purchased or developed in house does not affect the score.

Third, for firms competing for the InnoCom subsidy, there is an increase in the number of patents they hold (beyond a linear trend predicted from pre-2008 data). Importantly, the increase is especially great for those firms whose initial number of IPRs is fewer than six. Our main identification comes from a unique feature of the program: since the InnoCom has a numerical kink in the evaluation scoring formula - the subsidy does not increase for firms with the IPR count going beyond six.

Fourth, the average quality of the patents held by subsidy-competing firms has declined

[6]We call all IPRs holders as "firms". However, some NCEs are individuals or institutions.

following the InnoCom program. Since the kink point in the InnoCom program, we find that the quality decline is more pronounced for those firms with initial IPR lower than six.

Fifth, the InnoCom program has changed the patent trade pattern. After the launch of the program, the annual patent trade has increased by 18%. Patents sold by NCEs to the SCEs with an initially low IPR count has also risen as a proportion of all patent sales. The quality of traded patents declines. Especially, the decline is the greatest for those patents developed by non-subsidy-competing firms sold to subsidy-competing firms. This confirms that the subsidy program has altered the incentives faced by firms not directly competing for the subsidy.

Inspired by these facts, we build an equilibrium model to quantify the welfare impact of the InnoCom program. There are three additional channels that the policy can affect the welfare, besides the knowledge spillover of more innovations. The first is a direct effect - the SCEs may develop more low-quality patents in order to qualify for subsidies. The second is a trade-induced spillover effect - InnoCom has encouraged NCEs to produce more low-quality patents that can be sold to SCEs to compete for InnoCom subsidies. The third is a trade-enabled mis-allocation effect - InnoCom may induce a socially inefficient trade that assigns a patent from a high-value NCE user to a low-value SCE user. Both the second and third welfare loss are induced by the patent trade.

Based on our calibration, we find that InnoCom has greatly increased low-quality patents in share of total patents. The aggregate welfare that the IPRs can create declines by more than 1.9 billion RMB per year, which is about 57% of the total subsidy in the InnoCom program. Our model also suggests that trade-enabled welfare loss is quantitatively important - contributing to 1/3 of the total welfare loss associated with the program.

In the last two decades, very few countries can rival China in terms of the rates of growth in patent count. Even though China's income per capita is still below the world average, its

annual count of new patents, granted by domestic patent office, has exceeded all countries in the world since 2019.[7] Thus possible distortions from the the largest pro-innovation program, which is the focus of this paper, may have a significant aggregate implication.

Our paper contributes to three sets of literature. First, While the existing literature on patent trade focuses on its benefit, this paper highlights a potentially "dark" side of the trade. In the existing literature, patent trade improves welfare as it allows firms to specialize in what they are best at. For instance, Gans and Stern (2000) and Serrano (2010) point out the gains from patent trade when different firms have a different ability to commercialise the patents. Galasso et al. (2013) show the potential of patent trade to resolve commercial disputes without resorting to courts. Since there are gains from trade, frictions in trade may reduce welfare. Shapiro (2010) and Lemley and Shapiro (2005) argue that the patents are reallocated to entities that have the capacity to extract excessive royalty fees by holding up rivals. Akcigit et al. (2016) and Serrano (2018) highlight search frictions in the patent trade market. In most cases, lower frictions in trade raise welfare. In our case, lower frictions in patent trade reduce welfare due to distortions in patent subsidy programs.

Second, the paper contributes to the literature on the design of pro-innovation subsidy programs. Bloom et al. (2019) reviews a menu of common policy incentives and argues that the efficiency of various policies are very different. Subsidies in the tax code is common, especially for R&D activities. Bloom et al. (2002) and Wilson (2009) study the impact of the tax credit on the level of R&D investment in US. A special feature of the InnoCom policy is that it targets the IPRs rather than the R&D expenditure directly. Interestingly, many EU countries use patent boxes (tax cut on revenue linked to a patent), which bears some resemblance to the InnoCom policy. Although different countries have various designs of patent boxes, the literature find that the policy provides a chance for firms manipulate

[7] https://www.reuters.com/article/us-usa-china-patents/in-a-first-china-knocks-u-s-from-top-spot-in-global-patent-race-idUSKBN21P1P9.

stated revenues from patents to minimize their tax burden, hence may not be so efficient (Griffith et al. (2014); Gaessler et al. (2021)). Our paper shares a similar view: firms manipulate IPR count to maximize subsidies thus the InnoCom program creates distortions. Importantly, our paper suggests that the "idea market" may greatly amplify the welfare loss.[8]

Third, we enrich the literature on Chinese pro-innovation industrial policy by pointing out new channels of the welfare effects of the subsidy programs. Wei et al. (2017) emphasize a direct channel of welfare loss: while innovation come mostly from non-state-owned firms, the pro-innovation subsidies go mostly to state-owned firms. Chen et al. (2021) document the direct resource waste by firms competing for subsidies from re-relabelling non-innovation expenditures as R&D expenditure. König et al. (2020) study how frictions in input markets affect innovation. We add two new elements: the lack of ability to distinguish patents quality when subsidizing patent holders may generate welfare loss, and the patent trade market can amplify the loss.

The paper is organized as follows: Section 2 introduces the background of the InnoCom program and the data sets used in the paper. Section 3 provides documents four stylized facts on impacts of the InnoCom. The empirical patterns also motivate key assumptions used in our model that is laid out in Section 4. Using the calibrated result, Section 5 performs a number of counterfactual analyses. Finally, Section 6 concludes the paper.

[8]Bösenberg and Egger (2017), Ciaramella (2017) and Gaessler et al. (2021) also examine the patent trade under the patent box. They find that the policy generally can stimulate the trade, although the effect varies across countries. And they do not directly link the efficiency of patent box to the patent trade.

2 Background and Data

2.1 The Chinese InnoCom Program

The InnoCom program, introduced by the Chinese government in January of 2008, is intended to encourage innovation. The program awards subsidies in the form of a substantial reduction in corporate income tax (from 25% to 15% for three years) to approved firms in "industries of future." Firms can apply for a new award once an existing one expires.

As a form of industrial policy, the program covers 8 industries. Firms in these industries with high R&D intensities (which we call SCEs) can apply to the program.[9] In determining which firms will receive an award, a government committee (an office jointly established by local tax department and local bureau of science and technology) evaluates SCEs by assigning numerical scores in four areas: a count IPRs (up 30 points) , an ability to manage R&D (30 points), an ability to commercialize science and technology innovations (20 points), and growth potential (20 points). A subsidy (tax reduction) is awarded to a firm if it receives at least 70 points. While the last three categories are subjectively assessed, the IPR count appears objective. Table A3 in Appendix A explains the grading scheme in this category. If the firm has 6 or more IPRs (one invention patent is considered equivalent to 6 utility or design patents), the firm will get an "A" in this category, and receive 24-30 points.[10] When the IPR count decreases, firms will be marked from letter grade "B" to letter grade "E". Within each letter grade, the point difference is up to 6. Note that an applicant firm would receive the full 30 points when its IPR count reaches 6. Any higher count would not improve its chance of receiving the subsidy. On the other hand, fewer than 6 IPRs can

[9]Appendix A lists all the eligibility conditions to participate this program.

[10]IPRs include patents and software copyrights. Among three types of patents in China (invention, utility and design), invention is considered most innovative and most difficult to obtain. For the purpose of InnoCom, an invention patent is equivalent to 6 non-invention patents or software copyrights.

noticeably reduce its chance of receiving a subsidy. Because of the fear that SCEs use old and low-valued patents to apply for the subsidy, bureaucrat only counts IPRs granted within 3 years.

On average, the program each year provides a subsidy to over over 5,000 firms, about 60% of all SCEs, or 20% of all firms in the eight industries. The subsidy (tax reduction) is about 0.62 million RMB per firm-year, or 3.4 billion RMB in total per year.

We conjecture that bureaucrats are not able to tell the quality of IPRs. Some anecdotal evidence suggests that due to the InnoCom subsidy, a lot of agents start to sell service to help firms applying for IPRs. These agents advertises that they will prepare everything, including the ideas of IPRs and all related documents. It only takes a few months and the cost is as low as a few thousands RMB to get an IPR. Using the actual score of firms in the InnoCom program, we will confirm that the bureaucrat does not give high quality IPRs a higher score in the next section. Moreover, we will also confirm that the bureaucrat does not value in-house IPRs more than purchased IPRs later.

Compare InnoCom program with patent box

It may be interesting to compare the Chinese innovation subsidy program with similar programs in other countries. The patent box, which becomes more and more popular around the world, shares a number of similarities. Rather than providing a subsidy based on an input into innovation, R&D expense, both attemtp to look at some outcome of innovation activities.

Firstly, the main purpose and challenge are similar. These policy instruments are generally intended to encourage firms to hold qualified patents, since they directly increase benefits of successful R&D investments (patents). However, lacking the ability to distinguish high

quality innovations, both policies may be not efficient.[11] For the patent box, in principle, the bureaucrats can tell patents quality if they can separate revenues generated by patents with other revenues. However, in practice, firms have a large room to manipulate (Griffith et al. (2014)).

Moreover, similar with the InnoCom program, patent boxes in more than 10 countries allow purchased patents eligible for tax credits (Gaessler et al. (2021)). Such design in the patent box is to increase patents, especially high quality patents, in the local country.[12] We argue that if the bureaucrat cannot distinguish quality, allowing purchased patents may reduce the efficiency even further.

However, InnoCom program has several distinctive features. First, it has an explicit formula with a kink when counting IPRs. This feature greatly helps us for identifying the impact of the InnoCom program. Second, only new IPRs (granted within 3 years) are counted. So unlike the zombie patents phenomenon in the patent box, if patents are solely used for receiving subsidy, they will be discarded 3 years later. We can use renewal rates of patents 3 years after granted to measure the impact of the InnoCom program on patents quality. Finally, NCEs are excluded from the InnoCom program by nature. Hence a patent trade demand is induced between SCEs and NCEs, which can help us to study the welfare effect from the patent trade.

2.2 Data

We study the program in a large city (for which we have the requisite data). We utilize three data sets: administrative data about the firms from their tax records, patent assignment data

[11] Bloom et al. (2019) concludes that the patent box is the least effective tool to incentivize innovations.

[12] Bösenberg and Egger (2017) and Ciaramella (2017) find that a 1% increase in the tax rebate associated with the patent box could induce 10% increase in patent trade. But some countries require additional restriction on external patents (such as further development of patented invention). Within these countries, the effect of patent box on trade is not significant.

and software assignment data. The first data records firm-year level financial information (such as sales, employees, assets and etc.) and the industrial classification of the firms. The second and third data record the ownership of patents and software copyrights and any transfer (i.e., assignment) of the ownership through trade. Using this information, we construct the IPRs portfolio for each firm in each year. Importantly, we know more information about each patent, including whether it is renewed or not, its citation count, and identities of the buyer and the seller if a patent is sold.[13] Unfortunately, we do not have similar information on trade in software.

We use firm names to link up firm-level records in different data sets. To clean and standardize firm names, we follow these steps: (1) We trim all special symbols and punctuation marks that are not letters, characters or numbers. (2) We remove various corporate form, such as "limited corporation" or "subsidiary". (3) We convert all full-width letters and numbers into half-width ones. (4) All lower cases are changed in to upper cases.

Using the firm names filtered by the above steps, we merge the IPRs assignment information with the list of the subsidized firms. The overall matching performance is good. In particular, we can find 94% of firms that receive an InnoCom subsidy in 2008 in the patent assignment data. This ratio is comparable to Hu and Jefferson (2009). In the end, we have 90,539 IPRs holders (including patent holders and software copyright holders) in the sample city from 2005 to 2012. In addition, if holders are firms, we have their financial information from 2007 to 2011.

We then separate the IPRs holders into two groups: subsidy-competing-enterprises (SCEs), which satisfy the basic eligibility of the InnoCom program, and non-competing-entities (NCEs), which are firms, individual innovators, or other institutions that are not eligible for the program. Overall, IPRs holders in our sample can be grouped as Figure 2.

[13] In China, the patent needs to pay a renewal fee every year before the invalidation date. The fee depends on patent age. Overall, it is about 1,000 RMB per year.

3 Salient Data Patterns

In this section, we document a number of salient facts related to the InnoCom program, which will guide our subsequent model development. Since the InnoCom program treats an invention as equivalent to six other IPRs, we convert every invention patent to six other patents in our analysis.

3.1 While the quantity of patents has increased, the quality has declined

The growth of patents in China can be seen from the blue-circle line in figure 3, which plots the number of new patents per firm by year (left y-axis). The growth rate accelerates after 2008. The new patent count per firm includes both self-developed and purchased patents. The red-square line plots the share of external purchased patents (right y-axis). There is a noticeable jump in the share in 2008 from 1.2% to 2.8%. This figure suggests that the quantity of patents has not only been growing but has accelerated since 2008. Furthermore, patent trade is likely to have grown faster since 2008 as well.

We now look at patent quality, which we gauge in several different ways. Our baseline measure is the fraction of patents that are renewed three years after they are granted. Since renewing a patent requires an annual fee, the decision to renew a patent reflects the owner's judgement of whether the patent is valuable or not.[14]. Figure 4 plots the 3-years-out renewal rates of internal (self-developed) and external (purchased) patents granted within 2005 to 2012. The blue-circle line plots the renewal rate of in-house patents (those that are not traded three years after being granted). Their renewal rates are around 80% before 2008,

[14]The idea of using patent renewal rate as a proxy for the value of patents is first explored by Pakes (1986). A large literature follows this idea (such as Cornelli and Schankerman (1999), Lanjouw (1998), and Bessen (2008))

but start to decline from 2008. Overall, it declines by about 10 percentage points within the data sample.

The purchased patents, whose renewal rate is tracked by the red-square line, exhibit a higher renewal rate than in-house patents. This may come from a "selection" mechanism: with a positive transanction cost in the patent market, only good enough patents can overcome a positive transaction cost. But even for purchased patents, the average renewal rate still starts to decline after 2008. In other words, 2008 also appears to be a turning point for the average quality of patents.

Our second measure of patent quality is the 3-years-out citation count. In Figure 5.We plot the average 3-years-out citation count as a function of the year in which the patents are granted. We normalize the citation count in 2004 to be 0. Before 2008, the average citation count does not change very much. However, after 2008, the citation count starts to decline gradually. Hence we find a similar information as before: the patent quality declines after 2008.

As a third measure of patent quality, we estimate the marginal contribution of an additional patent to a firm's profit by regressing firm-level labor productivity (sales per employee) in a year on the number of newly obtained patents in the previous year, controlling for both industry and year fixed effects as well as firm location and ownership. To distinguish between the elasticity before 2008 and after 2008, we use a post-2008 dummy (inclusive) and interact it with the number of newly obtained patents. The result is reported in column 1 of table 1. We can see a difference in the marginal contribution of the patents to firm productivity. Before 2008, the labor productivity tends to increase by 4.1% following an additional patent. However, after 2008, the marginal contribution not only declines but the point estimates suggest a decline by 0.9% (0.050-0.041).

In column 2, we control for firm fixed effects (which subsume the industry, location, and

ownership dummies) and find a similar result. In this case, while the marginal contribution of patent ownership to firm productivity is not negative after 2008, it is smaller than before 2008 nonetheless.

To summarize, while the quantity of patents has grown faster after 2008, the quality has declined on average.

3.2 Bureaucrats can count but cannot differentiate quality

We have access to the detailed evaluation scores made by the bureaucrats on firms that have received the subsidy in 2008. We will use the data to evaluate a number of things. First, can the bureaucrats tell the difference between low and high quality patents? Second, do they care whether the patents are developed in-house by the applicant firms or purchased from other firms? Third, do they care about the quantity of patents up to a point?

We use two different proxies for patent quality: the 3 -years out citation count and the renewal rate in three years after being granted. Neither information is available to the bureaucrats at the time of reviewing a firm's application for an InnoCom subsidy. If the bureaucrats are able to make an informed judgement about the quality of the patents, they would pick up something that will be correlated with the subsequent citation count or renewable rate. In that case, they might assign a higher score to firms with higher-quality patents. On the other hand, if bureaucrats are unable to tell the quality of the patents, then their scores assigned to an applicant firm would be uncorrelated with the average quality of the patents in the firm's IPR portfolio.

We regress the points an applicant firm receives on the objective quality proxy of the IPRs portfolio, controlling the firm's observed characteristics (sales in 2007, ownership and industry) and beans of IPR count.[15] The regression sample is censored as only those firms

[15]The data is collected by the Municipal Science & Technology Commission of that city. It includes the

that have succeeded in obtaining a subsidy. However, for our purposes, the data censoring may not matter.

The results are reported in Table 2. The left hand side is the firm's point in the IPRs counts category (out of 30). In column 1, we see that firms with more IPRs do receive a higher score. However, once the IPR count reaches six, additional IPRs do not raise the score significantly. (The points assigned to firms with six IPRs and those more IPRs are the same statistically.) After controlling for the the IPR count, we see that higher quality patents in terms of subsequent citation count do not raise the points on the IPRs for the applicants.

In column 2, we measure the patent quality by the renewal rates of patents three years after being granted. We find similar results. That is, bureaucrats do not systematically assign a higher score to those firms with patents that will have a higher renewal rate. Again, the applicant firms would infer that the quality of their patents would not affect their chance of obtaining a subsequent. (Firms could care about patent quality for other reasons.)

In column 3 and 4, we use firm's total points (the sum of points across four categories) as the dependent variable, and re-run regressions similar with column 1 and 2. Again, there is no evidence that the bureaucrats can tell the quality of the patents as they do not assign more points to firms holding higher quality IPRs. In other words, a firm's chance to obtain a subsidy does not depend significantly on the quality of its patents.

Another interesting regressor is in-house patents as a share of an applicant firm's total IPR count. As this variable is never significant, we conclude that the bureaucrat does not distinguish between in-house and externally purchased IPRs. This validates our understanding of the InnoCom qualification methodology that counts the IPRs an applicant firm owns, regardless of where they come from. (The mastermind behind the InnoCom program may

grading information of the four categories, as well as other firm characteristics.

reason that it is a good thing if the program can manage to inspire innovation by firms that are not directly applying for an InnoCom subsidy.)

3.3 Subsidy-competing enterprises (SCEs) with a low initial IPR count show a faster growth in patents

Since the likelihood of receiving a subsidy is much higher for an SCE with 6 IPRs than one with fewer IPRs, but does not increase further once it reaches 6 IPRs, the policy may encourage firms that otherwise would have fewer than 6 IPRs to reach the count of 6. Figure 6 confirms this conjecture. The left graph of Figure 6 plots the density of the IPRs of those SCEs in 2007. The right graph of Figure 6 plots the density of these firms in 2008. As we can see, a notch point at 6 IPRs is clearly observed for 2008, the year when InnoCom was announced and implemented, but not in year 2007 when there was no InnoCom.

Is the change in the distribution of IPR count generated by the InnoCom program, or some other unobserved shocks? To examine a causal relation between the InnoCom program and change of SCEs' IPR count, we denote N_{it} as the number of newly acquired IPRs by SCE i in year t, and run the following regression:

$$ln(N_{it}) = \alpha_1 D_{it-1} + \alpha_2 D(t \geq 2008) + \alpha_3 D_{it-1} \times D(t \geq 2008) + s_{it-1} + \mu_i + \epsilon_{it} \qquad (1)$$

where D_{it-1} is a dummy which equals to 1 if both the count of IPR in the prior year $IPR_{it-1} < 6$ and $\text{Invention}_{it-1} = 0$, and 0 otherwise;[16] $D(t \geq 2008)$ is a dummy that equals to one in 2008 and afterwards, and zero otherwise; $s_{it-1} = 1$ if firm i has obtained a subsidy within the previous 3 years, and 0 otherwise; μ_i is a firm fixed effect that captures time-invariant firm heterogeneity, and ϵ_{it} is an iid random error.

[16] In the following empirical analysis, without further notification, we convert 1 invention to 6 IPRs.

While α_1 captures any general time-invariant difference in the number of IPRs between the two types of SCEs, α_2 captures any general increase in the number of IPRs after 2008 caused by factors common to all SCEs. The key coefficient of interest is α_3, which measures the difference in the number of newly acquired IPRs between those SCEs that had fewer than 6 IPRs and other SCEs. If those SCEs that had fewer than 6 IPRs in the previous year have a stronger motivation to acquire more IPRs than the other SCEs already with 6 or more IPRs, we would expect $\alpha_0 > 0$. Note that the above specification cannot capture the total effect of the InnoCom program on SCEs, but only compares the difference between SCEs with initial IPRs greater or smaller than 6.

An InnoCom subsidy is given to approved firms for three years. While applications for InnoCom subsidy are reviewed every year after 2008, those that have previously received a subsidy within three years would not need to apply again. We use s_{it-1} to account for possibly different incentives for such firms to increase IPRs.

In column 1 of Table 3, α_3 is 0.13. This means that the SCEs with fewer than 6 prior IPRS acquire 0.13% more IPRs than other SCEs. In the second column, we change the dependent variable to the number of newly self-developed patents.[17] We can see that these SCEs with fewer than 6 prior IPRs develop 0.04% more in-house innovation than other SCEs. As this number is smaller than α_3 in the first column, it implies that these SCEs also purchase more IPRs from patent trade market than other SCES.

In the third column, we switch back to IPR count. With the year fixed effects, all time-varying aggregate shocks that are common to all firms are controlled for, and D($t \geq 2008$) is dropped as it is absorbed by the year fixed effects. Importantly, the estimate of α_3 becomes even larger: those SCEs with fewer than 6 IPRs still increase their IPRs by about 0.22% more than other SCEs.

[17]Note that for software, we cannot distinguish in-house innovation and external purchase copyrights.

To check whether the SCEs with exactly 6 IPRs and those with more than 6 IPRs are different, we add a regressor $D(IPR_{it-1} = 6) \times D(t \geq 2008)$ in the fourth column of Table 3. $D(IPR_{it-1} = 6)$ is a dummy, which equals to 1 if the firm i has just 6 IPRs in year $t-1$ and 0 otherwise. The new coefficient compares SCEs with 6 IPRs and SCEs with more than 6 IPRs. While the coefficient on the new regressor is not statistically different from zero, α_3 is the same as before. This provides further confirmation that many SCEs have a strong incentive to reach 6 IPRs to qualify for an InnoCom subsidy, but not beyond.

To see if there is a pre-trend in the observed pattern, we estimate separate α_3 for each year and plot them in Figure 7. The circle-solid line represents the point estimates when the dependent variable is ln(IPR count), and capped spikes represent 90% confidence intervals.[18] Before 2008, α_3 is around 0, implying that the numbers of new IPRs between firms with more or lower than 6 IPRs are similar. However, α_3 begins to rise and becomes significantly greater than 0 since 2008. It means that SCEs with IPRs fewer than 6 starts to get more IPRs than other SCEs with 6 or more IPRs since 2008. This information is consistent with column 1 of Table 3.

Overall, α_3 gradually increases since 2008. This implies that incentives to get more IPRs for SCEs with lower than 6 IPRs become stronger over time. A possible explanation of the gradual increase could be the reaction time. Since firms have a short reaction time in 2008, they may not find enough IPRs to apply for the program. So the increase of IPRs at the beginning may not be as large as the increase in the later years.

To confirm our conjecture on "time of reaction", we again estimate α_3 year by year, but use ln(total patents) and ln(in-house patents) as dependent variables. Figure 8 plot α_3 of these two specifications. The circle-solid line represents point estimates when the dependent variable is total patent count, and the red bar represents point estimates when the dependent

[18]Note that we control dummies D($t \geq 2008$) and $D(IPR_{it-1} = 6)$. So we lost 1 year degree of freedom. The graph starts from 2006.

variable is in-house patent count. Capped spikes again are 90% confidence intervals. For the total patent count, the pattern is very similar with the Figure 7: the new patent count is significantly higher of SCEs with IPRs lower than 6 after 2008. However, before 2008, the new patent count is not significantly different between these two groups of firms. This again confirms our previous result that the InnoCom encourages firms to hold 6 IPRs.

Interestingly, the in-house patents pattern is different. Overall, the new in-house patents are similar between the two groups of SCEs before 2008. However, in the year 2008, the in-house patent count of SCEs with IPRs lower than 6 is lower than SCEs with 6 or more IPRs. Then since 2009, SCEs with IPRs lower than 6 self develop more patents than other SCEs. In other words, consistent with our "reaction time" conjecture, SCEs in 2008 mainly rely on external patents to increase their IPRs to 6. Since 2009, they gradually catch up, and self develop patents as well.

3.4 The average quality of patent of those owned by SCEs with initial low IPR declined more pronounced after 2008

As shown in Figure 4, the patent quality declines since 2008. If this decline is driven by the InnoCom program, in a similar logic as Fact 3, we expect to see that the renewal rate of patents held by SCEs with low initial IPR declines more significantly than other SCEs.

Let indicator variable $V_{ikt} = 1$ to indicate that SCE i chooses to renew patent k in year t. If $V_{ikt} = 0$, then that patent is not renewed. We consider the following regression.

$$V_{ikt} = \beta_1 D_{it-1} + \beta_2 D(\text{OY}_{ik} \geq 2008) + \beta_3 D_{it-1} \times D(\text{OY}_{ik} \geq 2008) + s_{it-1} + X_{kt} + \mu_i + \mu_t + \epsilon_{ikt} \quad (2)$$

where OY_{ik} is the year that firm i obtains the patent k. (If the patent is developed in-house, then it is the year of receiving patent approval. If the patent is purchased from

outside, it equals to the transaction year). $D(\text{OY}_{ik} \geq 2008)$ is a dummy, which equals to 1 if the patent k is obtained after 2008. D_{it-1} and s_{it-1} are defined in the same way as in equation (1). X_{kt} is a vector of observed characteristics of patent k, including patent's age, industry classification, and type (invention, utility or design). mu_i and mu_t are firm and year fixed effects, respectively. β_1 and β_2 measure the differences in the renewal rates between treatment group, those firms with fewer than 6 IPRs in the prior year ($D_{it-1} = 1$), and the control group ($D_{it-1} = 0$), and before and after 2008, respectively.

The key coefficient of interest is β_3, which measures differential change in the renewal rate of the patents owned by the treatment group of firms after 2008, relative to the control group of firms. If additional IPRs are acquired for the purpose of competing for a subsidy, rather than for their intrinsic scientific value, then the new IPRs are likely to be of low quality and would not be worth the extra renewal cost once the InnoCom review process is over. This would imply $\beta_3 < 0$. On the other hand, if the bureaucrats reviewing the InnoCom applications can identify the true quality of patents and take it into account in deciding which firms to award a subsidy, or if firms acquiring IPRs for their true scientific value for any other reason, then there may not be a relative decline in the quality of the patents. In that case, we may see $\beta_3 = 0$.

In column 1 of Table 5, β_3= -0.029 and is significantly different from 0. In other words, the patents owned by the treatment group of firms are indeed less likely to be renewed after 2008 relative to those owned by the control group.

In column 2, we include additional fixed effects for years of obtaining the patent. This allows different vintage of patents to have different quality for reasons unrelated to the InnoCom program. In this case, β_3= -0.045 and is significantly different from zero at the 5 percent level. The quality difference in the patents acquired by the treatment and control groups becomes more pronounced. In other words, the reduced form evidence is consistent

with the conjecture that those firms with fewer than 6 prior IPRs tend to acquire low-quality IPRs just to compete for a subsidy from the InnoCom program. Because many of these newly acquired patents do not have a high scientific or commercial value, firms often do not bother to pay a fee to renew them once the InnoCom application process is over.

In Figure 9, we estimate β_3 separately for each year to see if there is a pre-trend in the observed pattern. The circle-solid line represents the point estimates, and capped spikes represent 90% confidence intervals. We can see that the renewal rate of SCEs with low IPR is higher than that of SCEs with high IPR before 2008. This may suggest that patents are more valuable to firms with a small number of IPRs. However, after 2008, we can see that the renewal rate of SCEs with low IPR is significantly lower than SCEs with IPR greater than 6.

3.5 Patent sold from NCEs to those SCEs with a low initial IPR count grows fastest, but quality declines most significantly.

In the absence of patent trade, or if the purchased patent is not recognized in the InnoCom application process, then firms that do not satisfy the minimum eligibility conditions for a subsidy (NCEs) would not be affected by the pro-innovation policy. However, since patent can be traded, and the purchased patents can be used in SCEs' application for an InnoCom subsidy, the pro-innovation industrial policy can generate additional effects beyond a direct effect on the SCEs. Indeed, while the patent trade grew about 40% a year before 2008, the growth rate jumps to 76% a year after 2008.

To see the contribution of patent trade from different seller-buyer types, we separate the trade to 9 groups. Define a trade belongs to group 1 ($g = 1$) if both the buyer and seller are SCEs with fewer than 6 prior IPRs; Define a trade belongs to groups 2 or 3, if both the buyer and seller are SCEs with more than 6 IPRs, or both are NCEs, respectively. We define

similarly groups 4 to 9 considering all possible combinations of the seller's and buyer's types.

Table 4 reports the share of patent trade of each group in terms of from 2006, 2007 and 2012. We can see the shares in each group are quite similar from 2006 to 2007. However, the pattern is quite different in 2012. Specifically, the trade from NCEs or SCEs with IPR more than 6 to SCEs with IPR smaller than 6 increases sharply from 2007 to 2012. However, the trade selling from SCEs with IPR smaller than 6 declines significantly. These findings are consistent with incentives of the InnoCom program: the policy gives SCEs with IPRs fewer than 6 strong incentives to purchase patents externally, discourages them to sell patents. Meanwhile, NCEs's patents face an increasing demand to sell.

We then focus on quality of traded patents. Similar as fact 2, we separate traded patents into 9 groups. Table 6 reports the average renewal rate change before and after 2008.

Note that those patents purchased by SCEs with a low initial IPR country are presumably used to quality for the InnoCom subsidy. Their quality could be responsible to the incentive from the subsidy program. In contrast, the patents purchased by NCEs are used by NCEs for their intrinsic value. As they do not participate in the applications for an InnoCom subsidy, their quality is presumably not affected by the subsidy program.

A striking feature is that the quality decline for the post-2008 patents is pronounced in all patents except those that are purchased by NCEs. If the bureaucratic committee reviewing applications for an InnoCom subisdy can count the number of patents but cannot tell the quality of the patents, than it would not surprising that many SCEs with a low initial IPR count would buy many low-quality patents.

Note that the patents invented by NCEs but are not traded could include those produced with a hope to sell to SCEs to quality for a subsidy. In other words, even though these patents are not sold, their quality is still affected by the existence of the InnoCom program.

We want to emphasize that it may have other reasons that can explain the patent renewal

rate decline after 2008. However, if those factors are quantitatively large, we expect to see patents purchased by NCEs would also suffer a quality drop.

4 Model

We model the market equilibrium under the InnoCom program by incorporating the data patterns documented in the previous section. Firms first try to develop patentable innovations in-house, and patents trade may take place afterwards.[19] The subsidy policy, which counts the number of patents but does not adjust for quality (Fact 2 in the previous section), affects the aggregate welfare by altering the decisions on patent production and trade. We lay out a model that aims to capture the salient features of the subsidy program, and calibrate the model to quantify various channels through which the program affects the welfare. The potential benefit of the InnoCom program is to generate more patents, hence more knowledge spillover. In Appendix B, we show that the knowledge spillover is mainly concentrated within 8 InnoCom industries. Hence the model makes assumptions that are consistent with this observation as well. We calibrate the model to match the corresponding moments before the InnoCom program, as well as the relative moment change between SCE with low and high initial IPR after 2008 (Dif-in-Dif) to quantify the welfare impact of the program.

4.1 Environment

We consider three types of firms are in the economy. Subsidy-competing enterprises (SCEs) are firms in the eight targeted industries that have satisfy minimum R&D expenditure share

[19] We focus on patents and leave out software because we do not have data on ownership changes or trading in software. In Europe and the United States, many sophisticated and commercially valuable softwares receive a patent. But software registration in China is done through a different government agency, and we are not able to obtain reliable information on trade in software.

to be eligible to apply for a subsidy. We use subscript S to denote them and allow them to differ in their initial IPR. There are two types of non-subsidy-competing entities (NCEs): Those in the targeted industries but do not satisfy the minimum R&D expenditure share requirement, and those outside the targeted industries. We use subscripts $N(f)$ and $N(i)$ to denote them respectively.

Without loss of generality, we assume that an SCE may receive a subsidy from the InnoCom program if it owns a patent.[20] We normalize the measure of SCEs without full-filling the 6-IPR requirement to be 1, and denote β and m as measures of $N(f)$ and $N(i)$ respectively.[21] The measure of those NCEs outside the targeted industries, m, will be endogenously determined. Firms are heterogeneous in terms of their profits $\pi \in \{\pi_S, \pi_{N(f)}, \pi_{N(i)}\}$. Without loss of generality, we assume that an SCE may receive a subsidy from the InnoCom program if it has 1 patent.[22] Patents can differ by quality, denoted by x, but importantly, the probability of subsidy does not depend on x.

To capture the fact that some SCEs have full-filled the IPR requirement before the InnoCom program, we allow SCEs are also heterogeneous in terms of initial patents. $1-h$ SCEs do not have any patent, and h SCEs initially have 1 patent, with an average quality $\bar{x}$. Thus for the second type of SCEs, they may be subsidized even without any new inventions. We denote SCEs with and without initial patent as $S(h)$ and $S(l)$ respectively. For NCEs, we assume that all their initial patents are 0. This assumption is motivated by the fact that the average number of NCEs' patents is very small before 2008.

There are three stages in the economy. In the first stage, each firm tries to develop some

[20]This means we condense the 6-IPR requirement under InnoCom to one patent (such as an invention patent) in the model.

[21]SCEs with more than 6 IPRs initially will be explained later. In the following, without further notice, SCEs only refer those with low initial IPR.

[22]This means we condense the 6-IPR requirement under InnoCom to one patent (such as an invention patent) in the model.

patentable innovations in-house. We assume that each firm can invent at most 1 patent. It chooses an innovation success rate of θ (the probability of obtaining a patent), and a parameter λ that governs the likelihood that the patent is of a high quality. Formally, the patent quality distribution $G(x;\lambda)$ is a Bernoulli: $x = x_H$ with probability λ; $x = x_L$ with probability $1-\lambda$; and $x_H > x_L$. The innovation cost $C(\lambda,\theta)$, is increasing and convex in both λ and θ, and $C_{\lambda\theta} > 0$. The last inequality suggests that the marginal cost of increasing θ is higher for high quality patents. The innovation cost could be different between SCEs and NCEs, denoted by C_S and C_N, respectively.[23] This assumption captures the possibility that the minimum eligibility requirements of the InnoCom program distinguishes firms' innovation abilities. At the end of the first stage, some firms fail to achieve a patentable invention on their own. While some SCEs with an initial patent may have two patents, one with quality $\bar{x}$ and the other new patent with quality x.[24]

In the second stage, a market in patent trade opens. All NCEs and SCEs with more than 1 patent enter the market as sellers, and those SCEs without a patent enter the market as buyers..[25] A buyer and a seller will randomly meet with each other. The trade invovles with a fixed cost $\sigma \geq 0$. If the joint surplus of the trade (after considering the transaction cost) is positive, a trade will take place. For an SCE with two patents, we assume it will sell the new invented patent.

In the last stage, those SCEs with a patent more than 1 (regardless of the quality) will be subsidized with probability ρ. The subsidy is $T\pi_S$, where T is the subsidy rate (tax cut) of the InnoCom program. After receiving the subsidy, firms decide whether to renew patents

[23]Since we do not have the profit of non-firm NCEs, we do not distinguish the innovation costs between two NCEs.

[24]Hence firms in the model will have 0, 1 or 2 patents after the innovation stage.

[25]Motivated by the previous empirical findings, we assume NCEs will not buy patents from SCEs, and SCEs more than 6 patents will not buy any patents since the trade shares are small comparing to other trade shares.

at cost $c + \varepsilon$, where c is a constant which captures the common renewal cost of all patent holders. ε is an unobserved individual shock, which follows a normal distribution with mean 0 and standard deviation Ω_ε.[26]

For a firm within InnoCom industries (SCEs and $N(f)$), its profit, π, equals to Az, where z is the individual firm productivity $z \in \{z_S, z_{N(f)}\}$ and A is the endogenous aggregate productivity of the InnoCom industries, which depends on the total innovation in the economy. However, any individual firm takes A as given. That is, A captures the positive externality of innovation. Explicitly, we assume $A = A_0 K^\eta$, where A_0 is a constant, K is the aggregate knowledge capital, which will be explained later. $\eta \geq 0$ is the parameter of the knowledge spillover. An active patent x can bring in an additional profit, πx, to the patent holder.

Based our empirical findings in Table A6, we assume that other NCEs cannot enjoy the knowledge spillover from targeted industries. Their profit is $\pi_{N(i)} = z_{N(i)} x$ with an active patent, but 0 without an active patent. If this NCE is a non-firm entity (such as an individual inventor or a university research institute), $\pi_{N(i)}$ can be interpreted as the utility of holding a patent.

The timing of the model is summarized in Figure 10.

4.1.1 Production

We perform backward induction starting from the last stage. The value of a patent with quality x to a firm with profit π is $V(\pi, x) = E_\varepsilon (\pi x - \varepsilon - c)^+$, where $(.)^+$ equals to 0 if the value in the bracket is negative. E_ε means the expectation is taken over the random component of the renewable cost ε. The above equation implies a cutoff for the patent renewal decision: if the patent quality is bad enough, the firm will not renew the patent and the extra benefit from the patent is 0. Hence the renewal probability is $\Phi(\frac{Azx-c}{\Omega_\varepsilon})$, where Φ

[26] Here ε can be negative to capture motivations to renew patents for non-profit reasons.

is the CDF of a standard normal distribution.

With probability ρ, the SCE with patents more than 1 can receive subsidy. If an SCE has more than a patent, its total expected value (patent value + profit from other business+subsidy). Otherwise, an SCE cannot receive a subsidy. Consider an SCE with an initial patent, if it invents a new patent with quality x and still holds it to the production stage, its value is

$$V(\pi_S, x) + V(\pi_S, \bar{x}) + \pi_S + \rho T \pi_S$$

where the first two terms are the values from two patents, the third term is the firm value without patent, and the last term is the expected subsidy.

If it sells the new invented patent and holds only the old patent, we have its value as

$$V(\pi_S, \bar{x}) + \pi_S + \rho T \pi_S$$

Then consider an SCE without initial patents, its value with a patent is

$$V(\pi_S, x) = V(\pi_S, x) + \pi_S + \rho T \pi_S$$

However, if it does not have a patent, the value is only π_S.

The NCEs in the targeted industries are not eligible to apply for a subsidy. The values are $V\left(\pi_{N(f)}, x\right) + \pi_{N(f)}$ and $\pi_{N(f)}$ with and without a patent, respectively. Note that, based on Fact 6 from the previouis section, these firms can still benefit from a productivity spillover resulting from innovations of other firms in the same sector through a higher aggregate productivity A.

Finally, for those NCEs outside the targetted industries, the firm value with a patent is $V\left(\pi_{N(i)}, x\right)$, and its value without a patent is zero. They do not enjoy a knowledge spillover

from targeted industries (Fact 6 from the previous section).

4.1.2 Patent Trade

In the patent trading market, a seller and a buyer are randomly matched. The measure of SCEs without a patent (buyers) is $\left(1-\theta_{S(l)}\right)(1-h)$, where $\theta_{S(l)}$ is the self-innovation success rate of $S(l)$. Similarly, the measure of NCEs with a patent is $\beta\theta_{N(f)}+m\theta_{N(i)}+h\theta_{S(h)}$, where $\theta_{N(f)}$, $\theta_{N(i)}$ and $\theta_{S(h)}$ are success innovation rates of NCEs and $S(h)$ respectively. The buyer-seller ratio is

$$\delta=\frac{\left(1-\theta_{S(l)}\right)(1-h)}{\beta\theta_{N(f)}+m\theta_{N(i)}+h\theta_{S(h)}} \tag{3}$$

Denote a buyer meets a seller with probability $q_1(\delta)$ and a seller meets a buyer with probability $q_2(\delta)$, where $q_1'<0$ and $q_2'>0$.

When a buyer meets a seller with patent quality x and profit $\pi\in\{\pi_S,\pi_{N(f)},\pi_{N(i)}\}$, the trade surplus is

$$S(\pi_S,\pi,x)=V(\pi_S,x)+\rho T\pi_S-V(\pi,x)-\sigma \tag{4}$$

where σ is the random transaction cost, which is drawn from an exponential distribution with mean ϕ. We denote the CDF of σ as $F(\sigma)$. The trade will happen if $S(\pi_S,\pi,x)\geq 0$. An efficient is defined as the case $V(\pi_S,x)-V(\pi,x)>\sigma$. That is a trade that can really improve the value of the patent without any subsidy. When $\rho>0$, some inefficient trade (a trade to increase the chance to be subsidized, though the patent value declines) will happen.

The expected joint surplus is denoted as

$$S^{+}(\pi_S,\pi,x)=\int\left[V(\pi_S,x)+\rho T\pi_S-V(\pi,x)-\sigma\right]^{+}dF(\sigma)$$

where $(.)^{+}$ indicates that the trade will happen iff $S(\pi_S,\pi,x)\geq 0$.

After a trade, we assume that the surplus $S^{+}(\pi_S,\pi,x)$ is split equally between the buyer

and the seller. Hence upon their meeting, the expected value of buyer and seller would both increase by $\frac{1}{2}S^{+}(\pi_S, \pi, x)$.

4.1.3 Innovation stage

Firms are assumed to try to develop a patentable innovation in house before deciding on whether to go to the patent exchange market. A representative SCE without an initial patent, it chooses the innoation quality parameter λ_S and the probability of innovation success θ_S to maximize its expected value w_S,[27]

$$w_{S(l)} = \max_{\lambda_{S(l)}, \theta_{S(l)}} \theta_{S(l)} \int V(\pi_S, x)\, dG\left(x; \lambda_{S(l)}\right) + \theta_{S(l)} \rho T \pi_S + \left(1 - \theta_{S(l)}\right) TV_S + \pi_S - C_S\left(\lambda_{S(l)}, \theta_{S(l)}\right) \tag{5}$$

where TV_S is the value of purchasing patents for SCEs.

$$\begin{aligned} TV_S \;=\; & q_1 \frac{\beta\theta_{N(f)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}} \int \frac{1}{2} S^{+}\left(\pi_S, \pi_{N(f)}, x\right) dG\left(x; \lambda_{N(f)}\right) + \\ & q_1 \frac{m\theta_{N(i)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}} \int \frac{1}{2} S^{+}\left(\pi_S, \pi_{N(i)}, x\right) dG\left(x; \lambda_{N(i)}\right) + \\ & q_1 \frac{h\theta_{S(h)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}} \int \frac{1}{2} S^{+}\left(\pi_S, \pi_S, x\right) dG\left(x; \lambda_{S(h)}\right) \end{aligned}$$

The explanation of equation (5) is as follows. The first four terms are the value of having a patent. With probability θ_S, the SCE achieves a patent by itself. The quality of patent is drawn from distribution $G(x; \lambda_S)$. So the expected firm production value is $\int S^{+}(\pi_S, \pi_N, x)\, dG(x; \lambda_S)$ (the first term). Meanwhile, with probability ρ, the firm will be subsidized by $T\pi_S$ (the second term). The next term is the value if it purchases a patent externally: with probability $1 - \theta_S$, the SCE does not have an in-house patent and needs to purchase it. With probability $q_1 \frac{\beta\theta_{N(f)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}}$, it will meet an NCE $N(f)$, whose patent

[27] Note a slight abuse of notation here. Although x follows a Bernoulli distribution, we still use integration over the density $G(x; \lambda)$ when we define values.

quality x is drawn from distribution $G\left(x;\lambda_{N(f)}\right)$. With probability $q_1\frac{m\theta_{N(i)}}{\beta\theta_{N(f)}+m\theta_{N(i)}+h\theta_{S(h)}}$, it will meet an NCE $N(i)$. The patent quality follows a distribution $G\left(x;\lambda_{N(i)}\right)$. With probability $q_1\frac{h\theta_{S(h)}}{\beta\theta_{N(f)}+m\theta_{N(i)}+h\theta_{S(h)}}$, it will meet an $S(h)$. The patent quality follows a distribution $G\left(x;\lambda_{S(h)}\right)$. The fourth term is SCE's profit π_S from other source which is not affected by the patent renewal decision. The last term, C_S, is the innovation cost of an SCE.

For a representative SCE with an initial patent, it chooses quality of innovation $\lambda_{S(h)}$ and probability of success $\theta_{S(h)}$ to maximize its expected value $w_{S(h)}$.

$$\begin{aligned} w_{S(h)} &= \max_{\lambda_{S(h)},\theta_{S(h)}} \theta_{S(h)}\left[\int V\left(\pi_S,x\right)dG\left(x;\lambda_{S(h)}\right)+q_2\int\frac{1}{2}S^{+}\left(\pi_S,\pi_S,x\right)dG\left(x;\lambda_{S(h)}\right)\right] \\ &\quad +\pi_S+V\left(\pi_S,\bar{x}\right)+\rho T\pi_S-C_S\left(\lambda_{S(h)},\theta_{S(h)}\right) \end{aligned} \tag{6}$$

where the above equation suggests that with probability $\theta_{S(h)}$, the SCE can innovate one more patent, whose value equals to the production value plus the value from trade.

For a representative NCE in targeted industries, it chooses quality of innovation $\lambda_{N(f)}$ and probability of success $\theta_{N(f)}$ to maximize its expected value $w_{N(f)}$.

$$\begin{aligned} w_{N(f)} &= \max_{\lambda_{N(f)},\theta_{N(f)}} \theta_{N(f)}\left[\int V\left(\pi_{N(f)},x\right)dG\left(x;\lambda_{N(f)}\right)+q_2\int\frac{1}{2}S^{+}\left(\pi_S,\pi_{N(f)},x\right)dG\left(x;\lambda_{N(f)}\right)\right] \\ &\quad +\pi_{N(f)}-C_N\left(\lambda_{N(f)},\theta_{N(f)}\right) \end{aligned} \tag{7}$$

With probability $\theta_{N(f)}$, the NCE has a patent. In this case, it can always guarantee to get $\int V\left(\pi_{N(f)},x\right)dG\left(x;\lambda_{N(f)}\right)$. Moreover, with probability q_2, the NCE meets an SCE. In this case, the NCE receives an extra value from trade $\int\frac{1}{2}S^{+}\left(\pi_S,\pi_{N(f)},x\right)dG\left(x;\lambda_{N(f)}\right)$.[28] The

[28]Our model assumes that the NCEs innovate new patents and then sell to SCEs. A natural question could be that NCEs may directly sell old low value patents to SCEs without making any new innovations. However, in the data, we find that over 80% purchased patents are innovated within 3 years. We have tried to only use traded patents that are innovated within 3 years in the calibration. The results are similar.

third term is NCE's profit without a patent and the last term is its innovation cost. Note that its difference from the above $S(h)$ problem is that an NCE cannot get the subsidy.

For $N(i)$ firm, its problem is similar with equation (7) except that without a patent, its profit is 0.

$$\begin{aligned} w_{N(i)} &= \max_{\lambda_{N(i)},\theta_{N(i)}} \theta_{N(i)} \left[\int V\left(\pi_{N(i)}, x\right) dG\left(x; \lambda_{N(i)}\right) + q_2 \int \frac{1}{2} S^{+}\left(\pi_S, \pi_{N(i)}, x\right) dG\left(x; \lambda_{N(i)}\right) \right] \\ &\quad - C_N\left(\lambda_{N(i)}, \theta_{N(i)}\right) \end{aligned} \tag{8}$$

4.2 The Equilibrium

We define some useful aggregate variables first. In the last stage, the measure of $S(l)$ with one patent x is

$$\begin{aligned} p_S(x) &= (1-h)\,\theta_{S(l)} g(x; \lambda_S) + (1-h)\left(1-\theta_{S(l)}\right) q_1 \frac{\beta\theta_{N(f)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}} g\left(x; \lambda_{N(f)}\right) F\left(V(\pi_S, x) + \right. \\ &\quad + (1-h)\left(1-\theta_{S(l)}\right) q_1 \frac{m\theta_{N(i)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}} g\left(x; \lambda_{N(i)}\right) F\left(V(\pi_S, x) + \rho T\pi_S - V\left(\pi_{N(i)}, x\right)\right) \\ &\quad + (1-h)\left(1-\theta_{S(l)}\right) q_1 \frac{h\theta_{S(h)}}{\beta\theta_{N(f)} + m\theta_{N(i)} + h\theta_{S(h)}} g\left(x; \lambda_{S(h)}\right) F(\rho T\pi_S) \end{aligned}$$

where g is the density function of the quality distribution G. The first term is the measure of firms with in-house inventions x. The second to fourth terms are the measure of firms which purchase patents with quality x. With probability $q_S \frac{\beta\theta_{N(f)}}{\beta\theta_{N(f)} + m\theta_{N(i)}}$(or $q_S \frac{m\theta_{N(i)}}{\beta\theta_{N(f)} + m\theta_{N(i)}}$), an SCE without a patent meets an $N(f)$(or $N(i)$ and $S(h)$) with patent quality x. Depending on the realization of the transaction cost, the trade happens with probability $F\left(V(\pi_S, x) + \rho T\pi_S - V\left(\pi_{N(f)}, x\right)\right)$ (or $F\left(V(\pi_S, x) + \rho T\pi_S - V\left(\pi_{N(i)}, x\right)\right)$ and $F(V(\pi_S, x) + \rho T\pi_S - V$

The measure of NCEs in InnoCom industries with a patent x in the last stage is

$$p_{N(f)}(x) = \beta\theta_{N(f)} g\left(x; \lambda_{N(f)}\right)\left[1 - q_2 F\left(V(\pi_S, x) + \rho T\pi_S - V\left(\pi_{N(f)}, x\right)\right)\right] \tag{9}$$

where the term out of the bracket is the measure of $N(f)$ which innovate patents with quality x, and the term in the bracket is the probability that the patent x can not be sold either because sellers do not meet buyers or the transaction cost is too high.

Similarly, the measure of NCEs out targeted industries is

$$p_{N(i)}(x) = m\theta_{N(i)} g\left(x; \lambda_{N(i)}\right) \left[1 - q_2 F\left(V(\pi_S, x) + \rho T \pi_S - V\left(\pi_{N(i)}, x\right)\right)\right] \tag{10}$$

So for SCEs, the number of in-house patents is θ_S and the number of external purchased patents is $\int \left(p_S(x) - \theta_S g(x; \lambda_S)\right) dx$. For NCEs, the number of patents is $\int p_{N(f)}(x)\, dx + \int p_{N(i)}(x)\, dx$.

To allow for the possibility that innovation can increase knowledge spillover and improve the aggregate productivity, we define the aggregate knowledge capital as

$$K = \int x \left((1-h)\,\theta_{S(l)} g\left(x; \lambda_{S(l)}\right) + h\theta_{S(h)} g\left(x; \lambda_{S(h)}\right) + \beta\theta_{N(f)} g\left(x; \lambda_{N(f)}\right)\right) dx + h\bar{x} \tag{11}$$

Equation (11) suggests that high quality patents contribute more in the aggregate knowledge capital. The last term is the contribution from SCEs with initial IPR more than 6. Equation (11) also suggests that innovations from non-InnoCom industries do not contribute to the aggregate productivity of the InnoCom industries.

To close the model, we assume free entry of NCEs out of targeted industries:

$$w_{N(i)} = \kappa \tag{12}$$

where κ is the entry cost.[29]

Given the InnoCom policy ρ and T, and patents of SCEs before InnoCom h and $\bar{x}$, an

[29]In the data, most of new entrants after the InnoCom program is not from targeted industries.

equilibrium is defined as $\lambda_{S(l)}$, $\theta_{S(l)}$, $\lambda_{S(h)}$, $\theta_{S(h)}$, $\lambda_{N(f)}$, $\theta_{N(f)}$, $\lambda_{N(i)}$, $\theta_{N(i)}$, K, m and δ such that (i) The NCE and SCE's problems (5) to (8) are solved. (ii) Equations (3), (11) and (12) are solved.

4.3 Welfare Decomposition

In this subsection, we first define the aggregate welfare of the economy, and then show that the aggregate welfare can be decomposed into three sources.

The total subsidy is $TS = \rho T \pi_S (\int p_S(x)\,dx + h)$, where $\int p_S(x)\,dx + h$ is the number of SCEs with a patent. The subsidy may cause distortions on the government budget. We denote $\tau \geq 0$ as the shadow value of 1 unit subsidy on the government's fiscal budget. If $\tau = 0$, it means the government has a deep pocket.

The welfare is defined as the total firm value in the first stage taking out of the subsidy,

$$W = (1-h)\, w_{S(l)} + h w_{S(h)} + \beta w_{N(f)} - (1+\tau)\, TS \tag{13}$$

where we use the fact that the net value of other NCEs is 0 due to the free entry condition.

We can separate SCEs to firms that innovate patents by themselves, and purchase patents from NCEs. The total subsidies received by these three groups SCEs are

$$TS^{Self} = \rho T \pi_S (\theta_S + h), \quad TS^T = \rho T \pi_S \int \left[p_S(x) - \theta_{S(l)} g\left(x; \lambda_{S(l)}\right) \right] dx,$$

where TS^{Self} and TS^T denote subsidies to SCEs which self develop patents and purchase patents respectively. $TS^{Self} + TS^T = TS$.

We can then decompose the aggregate welfare as

$$W = \underbrace{\pi_S + \beta\pi_{N(f)} + hV\left(\pi_S, \bar{x}\right)}_{\text{knowledge externality}} + W_{SCE} + W_{reassignment} + W_{NCE} \tag{14}$$

where

$$W_{SCE} = \underbrace{(1-h)\left[\theta_{S(l)} \int V\left(\pi_S, x\right) dG\left(x; \lambda_{S(l)}\right) - C_S\left(\lambda_{S(l)}, \theta_{S(l)}\right)\right]}_{\text{(1) value from in-house innovation of SCEs}} - \underbrace{\tau TS^{Self}}_{\text{(2) fiscal cost}} \tag{15}$$

$$W_{reassignment} = \underbrace{2\left(1-\theta_{S(l)}\right)TV_S}_{\text{(3) surplus from patent trade}} - \underbrace{TS^T}_{\text{(4) subsidy to trade}} \tag{16}$$

$$W_{NCE} = h\left[\underbrace{\theta_{S(h)} \int V\left(\pi_S, x\right) dG\left(x; \lambda_{S(h)}\right) - C_S\left(\lambda_{S(h)}, \theta_{S(h)}\right)}_{\text{(5) value from innovation of } S(h)}\right]$$

$$\beta\left[\underbrace{\theta_{N(f)} \int V\left(\pi_{N(f)}, x\right) dG\left(x; \lambda_{N(f)}\right) -_N \left(\lambda_{N(f)}, \theta_{(f)}\right)}_{\text{(6) value from innovation of } N(f)}\right] + \tag{17}$$

$$\underbrace{m\left[\theta_{N(i)} \int V\left(\pi_{N(i)}, x\right) dG\left(x; \lambda_{N(i)}\right) - C_N\left(\lambda_{N(i)}, \theta_{(i)}\right) - \kappa\right]}_{\text{(7) value from innovation of N(i)}} - \underbrace{\tau TS^T}_{\text{(8) fiscal cost}} \tag{18}$$

We can see that the total welfare of the economy first should include the profits of all firms in targeted industries without any patents, and firm value of those SCEs who have already enough IPRs before the program. This part captures the knowledge spillover from the innovations.

W_{SCE} is the value of SCEs in-house patents. Its change comes from two sources. First, the in-house patent brings an expected benefit $\theta_S \int V\left(\pi_S, x\right) dG\left(x; \lambda_S\right)$ at innovation cost

$C_S(\lambda_S, \theta_S)$. Thus term (1) in equation (15) is the net value from in-house innovation. The term (2) captures the fiscal cost of subsidizing these SCEs.

$W_{reassignment}$ is the value from patents reassignment. Term (3) is the total joint surplus from trade, which includes the subsidy value. Term (4) removes subsidy receiving from patent trade. Hence $W_{reallocation}$ captures the efficiency gain from reallocating patents.

Finally, W_{NCE} is the value of NCEs' patents. It consists three components. Term (5) to term (7) are the values from patent sellers. Noticing that we consider the entry cost κ as a part of innovation cost since it captures the extensive margin of innovation from NCEs. The term (8) is the fiscal cost from subsidizing traded patents.

To summarize, we can see that the InnoCom program may change the aggregate welfare by: (1) Decreasing the innovation value since firms innovate more low quality patents and decrease the expected value $V(\pi, x)$ (entering W_{SCE} and W_{NCE}); (2) Distorting patent trade ($W_{reassignment}$). There are two opposite forces. On one hand, since inefficient trade ($\sigma > V(\pi_S, x) - V(\pi_N, x)$) may happen, the InnoCom program may decrease the welfare from trade. On the other hand, since more NCEs enter, it becomes easier to find a seller. The total number of trade and the number of efficient trade increase. Hence whether the InnoCom program would increase or decrease the efficiency of patent reallocation depends on which force dominates; (3) Creating fiscal cost; (4) Generating more knowledge spillover. We are interested at which channel dominates in the InnoCom program. Meanwhile, we are also interested at finding out more efficient ways to implement this program.

4.4 Calibration

To calibrate the model, we first impose a few parametric assumptions on some model elements. We assume that the innovation cost has the form

$$C_S(\lambda,\theta)=\frac{v_{0S}}{2}(\lambda_S\theta_S)^2+\frac{v_{1S}}{2}\theta_S^2,\quad C_N(\lambda,\theta)=\frac{v_{0N}}{2}(\lambda_N\theta_N)^2+\frac{v_{1N}}{2}\theta_N^2$$

v_{0S}, v_{1S}, v_{0N} and v_{1N} are parameters that are different between SCEs and NCEs. In the above cost functions, the innovation cost is increasing and convex in θ and λ. Meanwhile, when λ increases, the marginal cost of increasing θ is higher.

The matching function is assumed to be the form

$$q_1=\frac{1-\exp(-b\delta)}{\delta},\ \ q_2=1-\exp(-b\delta)$$

where b is a parameter that measures the matching efficiency.[30]

For simplicity, we assume $x_L=0$, which means that the low quality patent does not bring any extra profit to the holder. Since the measure of SCEs is normalized to 1, we set $\beta=2$ to match annual average number of NCEs in the InnoCom industries over the sample. We also set $h=0.22$ to match those SCEs with 6 or more IPRs before InnoCom program.

To solve the model, we need to know the following parameters: (1) patent quality x_H; (2) the mean and standard deviation of renewal cost c and Ω_ε; (3) firm productivity $z_S, z_{N(f)}$ and $z_{N(i)}$; (4) the innovation cost parameters v_{0S}, v_{1S}, v_{0N} and v_{1N}; (5) the matching efficiency b; (6) the average patent transaction cost ϕ; (7) the entry cost κ; (8) the aggregate productivity parameters A_0 and η; (9) subsidy parameter ρ and T; (10) the fiscal cost parameter τ; and (11) patents quality of SCEs with initial high IPRs $\bar{x}$.

[30]This matching function is widely used in the search literature, such as Petrongolo and Pissarides (2001).

We assign some parameters at the first. For SCEs and NCEs within targeted industries, we can see their profits. So we normalize $z_S = 1$ and calibrate $z_{N(f)} = 0.9$ to match the average relative profit between these two groups of firms within the sample.[31] Since a lot of other NCEs are not firms, we can not directly observe their benefits of holding patents. We calibrate $z_{N(i)}$ internally.

For the subsidy policy, we set $\rho = 0.6$ to match the observed subsidy possibility within SCEs. We also set $T = 0.1$ which implies the InnoCom firms enjoy a 10% tax cut.

We calibrate $\eta = 0.01$ to match the elasticity of column 2 of Table A6.[32] Finally, Chen et al. (2021) estimates the cost of the InnoCom program budget with $\tau = 0.2$.[33] Ming (2009) estimates the τ in a reduced form way, and find τ is between 0.2 to 0.4. We set $\tau = 0.2$ in our baseline analysis. We explore the robustness of η and τ later.

Mapping model to the data

For the rest 13 parameters,[34] We calibrate them to match 13 moments in the data. A lot of factors besides the InnoCom program may change after 2008. Thus we calibrate our model to match data moments before the InnoCom program, and the relative difference between SCEs with initial low IPR and high IPR after the InnoCom program. Our basic idea is that we the relative change of patents quantity and quality of SCEs with initial IPR lower than 6 and higher than 6, as identified in Table 3 (column 3) and Table 5 (column 2), capture the

[31] Hence SCEs are 10% larger than other firms in the same industry.

[32] Notice that K is defined as the patent counts weighted by x In the model. While in Table A6, K is defined as patent counts weighted by renewal rates. In principle, if we have several periods in the model, we can compute the knowledge capital as Table A6, and regress $\ln A$ on it. We then can choose η to make the regression coefficient from the model be 0.01. However, since we only calibrate two periods (before and after 2008) in the model, we cannot do this exercise but simply impose $\eta = 0.01$. We will explore the robustness in Figure 11.

[33] They get this estimate by assuming the utility from public spending is the same between China and US. Using the average tax rate in China to infer the public spending, τ can be estimated.

[34] They include c, x_H, v_{0S}, v_{1S}, v_{0N}, v_{1N}, b, ϕ ,κ, $z_{N(i)}$, Ω_ε, A_0 and $\bar{x}$. The numerical details are provided in Appendix C.

most significant effect of the InnoCom program.[35]

We start from explaining the identification intuition of the innovation cost parameters (v_{0S}, v_{1S}, v_{0N}, v_{1N}). They directly determine patents quality and patent counts. So we calibrate them to match the counts and renewal rates of self-developed patents for SCEs and NCEs.

$\bar{x}$ is calibrated to match the renewal rates of SCEs with initial IPR higher than 6. Parameters b and ϕ determines the patent trade market frictions. We calibrate b to match the number of purchased patents of SCEs because it directly changes the number of trade. Meanwhile, since $\phi > 0$, it generates a selection effect that the high quality patents are more likely to be traded. So we calibrate ϕ to match renewal rates of external patents of SCEs, which will reflect the quality of traded patents. The parameter κ is calibrated to match the number of NCEs. Ω_ε, the standard deviation of the renewal cost shock, is calibrated to match the dispersion of renewal rates before and after the policy. Lastly, A_0 and $z_{N(i)}$ can be considered as sector productivity shocks of InnoCom industries and other industries. We then calibrate them to match average before tax profit of Innocom industries and the renewal rate of other NCEs before/after the policy. (Note that we cannot directly observe profits of other NCEs, so we use renewal rates to infer $z_{N(i)}$). x_H and c are calibrated to match the profit difference between SCEs with a patent and without a patent before and after 2008. Intuitively, when c increases, more patents will not be renewed. Hence the profit with and without a patent would decrease.

The parameters and model fit are shown in Table 7. The model fits the data well. The model value is 10,000 RMB. First, $x_H = 0.17$. It suggests that a high quality patent can increase the firm's profit by 17%. Second, the renewal cost c is about 0.77 with standard

[35]However, the InnoCom program may also change any fundamental parameters, which may underestimate the impact of the program. For instance, anecdotal evidence suggests that the InnoCom program increases the number of patent trade intermediaries, which may change the trade frictions b and ϕ. We will consider some robustness extensions later.

deviations 7.23. In China, a patent holder needs to pay about 1,000RMB (0.1 in model value) every year to renew the patent. However, the renewal cost not only include the official renewal fee, but also other indirect renewal cost (such as the legal cost to protect patent rights). So our estimate of c is much greater than 1,000RMB.

From Table 7, we can see that SCEs have smaller innovation costs than NCEs in both quality and quantity dimensions (v_0 and v_1). This difference may reflect the fact that pre-requirements of the InnoCom program can select out firms with lower innovation costs.

Model Validation

We perform a few validation tests. First, we test whether our model can capture the increase of the trade after the InnoCom program. After de-trending the patents trade using the average growth rate before 2008, we find that the trade purchased by SCEs with IPR lower than 6 from NCEs and SCEs increase additionally by 5% and 2%. The first two rows of Panel B in Table 7 reports the increase in our model, which is quite close with the data. The greater increase of trade from NCEs to SCEs is because that the number of NCEs increases after the program.

Secondly, we look at the increase of patents. In our model, an SCE with initial IPR higher than 6 would innovate more patents since the value to sell patents increases under the InnoCom program. The first row of Panel B in Table 7 compares the increase of patent count before and after the subsidy in the model with that in the data. We can see that in the model, SCE with high initial IPR innovates 1% more patents, while the data value is about 7%.[36] This may suggest that an aggregate trend other than InnoCom program induces firms to invent more patents.

Similarly, we do not target the innovation of NCEs after InnoCom program. Our model

[36]To get this number, we use the average growth rate of patents before 2008 to detrend the patent count after 2008.

predicts that NCEs would increase their patents by 2% after InnoCom program since they can sell more patents. However, the data suggests a slightly larger increase of NCEs' in-house innovations.

5 Welfare and Policy Analysis

To understand the effect of InnoCom better, we focus on the economy with and without the InnoCom program in Table 8. In the first column, we use parameters in Table 7 and assume the subsidy does not exist ($\rho = 0$, a "laissez faire" economy). In the second column, we consider an economy with the InnoCom program (as the real world). And the third column reports the difference between the InnoCom economy and the "laissez faire" economy. In both scenario, we report the total welfare and decompose it into several sources as equation (14). The first row is the total subsidy, which is about 3.4 billion RMB per year after 2008.[37] The second row is the average patent quality x. Without the subsidy, the average x is about 4.37%. However, it declines to 2.01% with the InnoCom subsidy since firms focus on patent count rather than quality.

The next a few rows reports the aggregate welfare, and four decomposition parts in the welfare equation (14). Row (a) is the aggregate profit of firms in 8 InnoCom industries (without considering the value from holding patents by themselves). Since quality of patents declines, although more patents are created, the aggregate knowledge capital slightly declines, and its contribution to productivity decreases. So the total non-patent profit decreases by 0.01 billion RMB.

Row (b) is W_{SCE}, the net value of SCEs' in-house patents, which is the SCE innovation value minus the fiscal social cost of TS^{self}. This is the direct welfare effect of the InnoCom

[37]The annual total InnoCom subsidy for this city is about 3.4 billion RMB. In our model, we scale the measure of SCEs to match the total subsidy in the data.

program. Since SCEs waste too much resource to produce low quality patents, W_{SCE} declines by 1.28 billion RMB.

Row (c) is value from re-assigning patents from inventors to other patent users. This number declines by 0.27 billion RMB, suggesting that a lot of inefficient trade is induced to receive subsidy.

ROw (d) is the net value of NCE's developed patents, which equals to the NCE innovation value minus the fiscal social cost of TS^T. This value declines by 0.46 billion RMB because NCEs waste resource to produce low quality patents to sell.

Overall, we can see that the aggregate welfare decrease by 2.02 billion RMB. Notice that most of the welfare loss, about 63% (1.28/2.02) comes from the direct channel that SCEs innovate low value patents. However, the patent trade market significantly amplifies the welfare loss by about 50% ((0.27+0.46)/1.28).

Robustness

The aggregate welfare depends on two key parameters: the externality η and the shadow value of the fiscal budget τ. We then explore another robustness check: what is the combination of η and τ that makes the InnoCom program welfare neutral after 2008 (that is the welfare with subsidy (column 2 of Table 8) equals to the welfare without subsidy (column 3 of Table 8)). Figure 11 shows the "welfare break even" τ for any given η, holding all other parameters the same as column 2 of Table 8). When η increases, the knowledge externality increases, so we can suffer a higher fiscal cost τ that makes the subsidy welfare neutral. If τ is above/below the solid line in Figure 11, the InnoCom program generates welfare loss/gain. In the baseline case ($\eta = 0.01$), the InnoCom program will be welfare enhanced only if $\tau \leq -0.37$ (1 dollar subsidy's cost is only 63 cents). Lucking et al. (2019) estimates that the knowledge spillover is bounded above by 0.2. Even in this case, the "welfare break

even" τ is still negative. However, according to Chen et al. (2021) and Ming (2009), a reasonable estimate of τ in China is from 0.2 to 0.4, which means that the InnoCom program can generate welfare gain only if η is very large (greater than 0.3), which is very unlikely.

To sum up, we find that the InnoCom program is very likely to hurt the aggregate welfare, and the patent trade market plays a quantitatively important role in the welfare loss.

Alternative subsidy policies

We then consider alternative subsidy policies in Table 9. In each column, we consider an economy with parameters are the same as Table 7, but subsidizing firms in a different way.

First, given the aggregate welfare loss mainly comes from the external purchase, we consider an alternative policy that only counts self-developed patents. The policy still subsidizes firms with $\rho = 0.6$.[38] The first column of Table 9 reports it. Comparing to column 2 of Table 8), we can see that the total subsidy declines to 2.75 billion, and the patent quality increases to 3.45%. Thanks to the improvement of the patent quality, the aggregate productivity barely does not change, although innovation cost declines. Overall, the aggregate welfare increases from 365.66 to 365.97. Thus the InnoCom program can be more efficient if only counting the internal patents. However, the welfare is still lower than not subsidizing firms at all (column 1 of Table 8)).

In the second column of Table 9, we consider an policy that NCEs in InnoCom industries ($N(f)$) can also be subsidized with probability 0.6 (such as removing pre-requirements of the InnoCom program). Total subsidy and innovation cost are higher since more firms are subsidized. Meanwhile, the patent quality further declines to 1.81%. However, the aggregate productivity barely changes. In the end, the total welfare declines to 360.47 billion RMB. This large decline mostly comes from W_{NCE}, which now has three components. Besides the

[38]Notice that the patent trade market still opens, but SCEs can get subsidy only with self-developed patents.

NCE innovation value and the social cost of fiscal subsidy to traded patents, there is one more term: the social cost of subsidy to NCEs, which is about 2.15 billion RMB. This is because that NCEs are good at producing low quality patents. They can develop a patent very easily and receive subsidy. Thus the total subsidy is now very large, about 12.88 billion RMB. In other words, this type of subsidy policy is extremely inefficient since we subsidize too much.

In the above two experiments, we fix ρ, so the total budget of the subsidy changes. We then explore similar policy designs as column 1 and 2, but fix the total subsidy to be 3.4 billion RMB. In column 3, we consider the policy that only allows in-house patents to claim subsidy. A fixed budget implies that ρ is about 0.7. Hence more SCEs will be subsidized. The patents quality slightly decreases since SCEs understand that as long as they have a patent, it is very likely to be subsidized. So they sacrifice more on patents quality. However, because more patents are generated, the aggregate productivity increases. In the end, the aggregate welfare, comparing to the old policy design, increases by 0.60 billion RMB (366.26-365.66). Hence by only counting internal patents, the InnoCom program can do better, but it still generates welfare loss.

In column 4, we report the economy when subsidizing all firms in targeted industries but fixing the total budget. This implies that ρ is only about 0.32, much smaller than before. Since the total subsidy is fixed at 3.4, the welfare is higher than column 2. But we can still see that it is worse than only subsidizing SCEs. This is because that NCEs are very good at producing low quality patents. If they have chance to be subsidized directly, they will produce more low quality patents. This will decrease the aggregate productivity, as well as the total welfare of the economy.

Optimal subsidy policies

We then explore whether the InnoCom program can be more efficient by making the program more competitive. The result is in the first column of Table 10. Comparing it with column 2 of Table 8), we search ρ to maximize the total welfare. We find that the optimal ρ is very small, about 0.001. This means that the if the policy is designed as such, it may be not good to subsidize any firms.

The essential reason that the InnoCom program creates welfare loss is that the bureaucrat cannot distinguish high quality patents and low quality patents. To see this point clearly, we then consider a counterfactual experiment that the government can distinguish patents quality. Let ρ_H and ρ_L be the probabilities of being subsidized when holding patents with quality x_H and x_L. We then search ρ_H and ρ_L to maximize the welfare. The second column of Table 10 reports the result. We find that when $\rho_H = 0.48$ and $\rho_L = 0$, the welfare is maximized. In this case, the government does not want to subsidize low quality patents since they cannot improve the aggregate knowledge capital. However, the government wants to subsidize high quality patents more intensively. Comparing to column 2 of Table 8, the total subsidy declines but the patent quality increases. Overall, the aggregate welfare increases by 2.59 billion (368.25-365.66), or about 0.7% of the industry total profit (2.59/364.30). This increase mainly comes from the aggregate knowledge spillover.

In the third column of Table 10, we consider whether it is better to accept purchased patents for the subsidy. Comparing to the previous column, we find that the government slightly increases the ρ_H. It is because SCEs have a relatively high cost of producing low quality patents, hence are more likely to have high quality patents. This point is also reflect on the average x, which increases from 4.05% to 5.2%. However, due to fewer patents are produced, the aggregate productivity and the total industry profit (without patents) declines slightly. Overall, we can see that the total welfare increases, which mainly comes from the

increase of W_{NCE}. This change comes from the way we model the trade market. We assume that the trade market is a random search-match market with a free entry condition. Thus the well-known congestion effect exists: the entry of new NCEs would reduce the probability of incumbent NCEs to sell their patents. If the bureaucrat does not count external patents, fewer NCEs will enter the market hence this excess entry problem can be alleviated. So in our model, it is better only counting internal patents even the bureaucrat can tell quality difference.

6 Conclusion

In this paper, we study how the patent subsidy policy, the InnoCom program, change the aggregate welfare. We show that the subsidy policy decreases the value of patents either through declining the quality of new granted patents or through the inefficient trade of patents. Overall, we find the InnoCom program can reduce the aggregate welfare, and the patent trade market can amplify the welfare loss significantly. Thus it is important to consider the patent trade market when we design a pro-innovation policy which directly subsidizes patent holders.

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Tables and Figures

Table 1: Labor Productivity and Patent

	$\ln(\text{labor prod}_{it})$	$\ln(\text{labor prod}_{it})$
$(\text{New patent}_{it-1}) \times (t \geq 2008)$	-0.060***	-0.037*
	(0.021)	(0.022)
New patent_{it-1}	0.041***	0.043**
	(0.013)	(0.025)
Year FEs	Y	Y
Firm FEs		Y
Obs.	31,332	10,995
Adj. R2	0.42	0.77

Notes: This table shows the marginal change of firm labor productivity when the patent count increases.

Table 2: Correlation between Evaluation Points and IPRs Quality

	(1)	(2)	(3)	(4)
	PT in IPR count		Tot. PT	
	Ave. citation	Ave. renewal rate	Ave. citation	Ave. renewal rate
Quality proxy	0.030	0.015	0.085	-3.916
	(0.025)	-0.051	(0.061)	(2.516)
ln($Sales$)	0.079***	0.067**	0.776**	0.801***
	(0.027)	-0.038	(0.312)	(0.355)
In-house IPR sh.	0.001	-0.002	-0.087	0.885
	(0.003)	-0.003	(0.047)	(0.591)
(IPRs=1-2)	0.000	0.000	0.03	0.03
	(0.000)	(0.000)	(0.02)	(0.02)
(IPRs=3)	0.805	0.241	1.185	0.985
	(0.784)	(0.471)	(1.318)	(1.018)
(IPRs=4)	1.092**	2.479***	2.992**	2.122**
	(0.338)	(0.702)	(1.338)	(1.088)
(IPRs=5)	3.096***	6.207***	5.001***	5.771**
	(0.427)	(0.661)	(2.072)	(2.220)
(IPRs=6)	6.665***	10.018***	8.561***	10.111***
	(0.274)	(0.523)	(2.470)	(3.709)
(IPRs> 6)	6.813***	10.163***	8.999***	10.195***
	(0.321)	(0.492)	(3.021)	(3.712)
Industry/ownership	Y	Y	Y	Y
Obs.	2,470	2,470	2,470	2,470
Adj. R2	0.62	0.62	0.16	0.18

Notes: This table shows the correlation between 2008 subsidized firms' patents quality and their evaluation grades by the bureaucrat. The dependent variables are points in IPR count (column 1 and 2) and total points (column 3 and 4) in the InnoCom evaluation. Quality proxy is the average citation (column 1 and 3) or renewal rates (column 2 and 4) of patents owned by a firm. In-house IPR share is the share of self-developed IPRs. In each regression, we control ownership and industry.

Table 3: Number of New IPRs in Relation to the Timing of InnoCom Policy

	(1) ln(IPR)	(2) ln(Self-dev.patent)	(3) ln(IPR)	(4) ln(IPR)
$D_{it-1} \times D(t \geq 2008)$	0.129**	0.043*	0.217***	0.213***
	(0.043)	(0.024)	(0.027)	(0.047)
$D(IPR_{it-1} = 6) \times D(t \geq 2008)$				-0.046
				(0.053)
$D(t \geq 2008)$	Y	Y		Y
D_{it-1}, s_{it-1}	Y	Y	Y	Y
Firm FEs	Y	Y	Y	Y
Year FEs			Y	Y
Obs.	10,477	10,407	10,477	10,477
Adj. R2	0.75	0.78	0.77	0.77

Notes: This table presents the estimation results of the equation (1) of SCEs. The observation is at firm-year level. N_{it} is the new obtained IPRs of firm i in year t. $D_{it} = 1$ if $IPR_{it} < 6$ and invention$_{it} = 0$. $s_{it} = 1$ if the firm is subsidized within three years. Standard errors are reported in the parentheses and clustered at the firm-year level. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Patent Trade Shares

Seller \ Buyer	SCEs IPRs<6	SCEs IPRs≥6	NCEs
	2006		
SCEs IPR<6	0.075	0.003	0.021
SCEs IPR≥6	0.068	0.011	0.075
NCEs	0.198	0.031	0.518
	2007		
SCEs IPR<6	0.081	0.001	0.016
SCEs IPR≥6	0.045	0.012	0.068
NCEs	0.154	0.020	0.603
	2012		
SCEs IPR<6	0.006	0.001	0.005
SCEs IPR≥6	0.136	0.029	0.056
NCEs	0.328	0.083	0.356

Notes: This table shows the share of patent trade from 9 categories based on buyers' and sellers' characteristics. The sum of all 9 cells within one year equals to 1.

Table 5: The Renewal Rates of New Obtained Patents in Relation to the Timing of InnoCom Policy

	(1) V_{ikt}	(2) V_{ikt}
$D_{it-1} \times (\text{OY}_{\cdot ik} \geq 2008)$	-0.029**	-0.045**
	(0.015)	(0.022)
$(\text{OY}_{\cdot ik} \geq 2008)$	Y	
D_{it-1}, s_{it-1}	Y	Y
Patent char/Firm FEs/Year FEs	Y	Y
OY. FE		Y
Obs.	159,510	159,510
Adj. R2	0.42	0.51

Notes: The observation is at firm-patent-year level. $V_{ikt} = 1$ if the firm i renews patent k in year t, and 0 otherwise. $\text{OY}_{\cdot ik}$ is the year of obtaining patent k. $D_{it} = 1$ if $IPR_{it} < 6$ and $\text{invention}_{it} = 0$. $s_{it} = 1$ if the firm is subsidized within three years. Patent characteristics include patent age, industry classification and type (invention, utility or design). Standard errors are reported in the parentheses and clustered at the firm-patent-year level. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: 3yrs Renewal Rate of Traded Patents

Seller \ Buyer	SCEs IPRs<6	SCEs IPRs≥6	NCEs
	2006-2007		
SCEs IPR<6	0.973	0.981	0.982
SCEs IPR≥6	0.951	0.972	0.962
NCEs	0.960	0.971	0.954
	2007-2012		
SCEs IPR<6	0.951	0.941	0.972
SCEs IPR≥6	0.873	0.972	0.941
NCEs	0.710	0.943	0.891

Notes: This table decomposes the 3yrs renewal rate of traded patents based on buyers' and sellers' characteristics.

Table 7: Parameters and Model Fit

Param.	Value	Moments	Data	Model
		Panel A: Parameters and targeted moments		
Before policy				
v_{1N}	41.22	NCE self-developed patents	2.56	2.56
v_{0N}	73.21	Renewal rate of NCE patents	0.77	0.77
v_{1S}	37.14	SCE with IPR<6 self-developed patents	0.99	0.99
v_{0S}	70.09	Renewal rate of SCE with IPR<6 self-developed patents	0.91	0.91
$\bar{x}$	0.19	Renewal rate of SCE with IPR≥6 self-developed patents	0.92	0.92
b	4.07	External patents per SCE	0.88	0.88
ϕ	0.14	Renewal rate of SCE with IPR<6 external patents	0.99	0.99
κ	48.19	NCE/SCE	6.86	6.86
A_0	2.01	InnoCom industry profit	4.85*	4.85
$z_{N(i)}$	6.77	Renewal rates of other NCEs	0.72	0.72
Ω_ϵ	7.23	Sd of renewal rates	0.15	0.15
After policy				
x_H	0.17	Dif-Dif: ln(patents) of SCEs with IPR< 6/≥ 6	0.23	0.24
c	0.77	Dif-Dif: renewal rate of SCEs with IPR< 6/≥ 6	-0.04	-0.05
		Panel B: Untargeted moments		
		Δ ln(Trade) from NCE to SCEs with IPR< 6	0.05**	0.04
		Δ ln(Trade) from SCEs with IPR≥ 6 to SCEs with IPR< 6	0.02**	0.02
		Δ ln(patents) of SCEs with IPR≥ 6	0.07**	0.01
		Δ ln(patents) of NCEs	0.03**	0.02

Notes: This table reports the parameters and model fit by comparing the moments in the model and the data. The moments before and after the subsidy are computed using data from 2005-2007 and 2008-2012 respectively. The model value is 10,000RMB.

* We use the average profit per worker of the InnoCom industries.

** These two numbers are computed by detrending the patent counts after 2008 using average growth rates of patent counts before 2008.

Table 8: Welfare Decomposition

	(1) Laisse Faire $\rho = 0$	(2) InnoCom $\rho = 0.6$	(2)-(1) Difference
Subsidy	0	3.40	3.40
Ave. quality x	4.37%	2.01%	-2.32%
(a) Industry Profit (aggregate prod):	364.31	364.30	-0.01
(b) W_{SCE} ((b.1)+(b.2))	0.88	-0.40	-1.28
(b.1) SCE innovation val.	0.88	0.12	-0.76
(b.2) Fiscal social cost $-\tau TS^{self}$	0	-0.52	-0.52
(c) $W_{reassignment}$	0.01	-0.26	-0.27
(d) W_{NCE} ((d.1)+(d.2))	2.36	1.90	-0.46
(d.1) NCE innov val.	2.36	2.24	-0.12
(d.2) Fiscal social cost $-\tau TS^{T}$	0	-0.34	-0.34
Welfare ((a)+(b)+(c)+(d))	367.68	365.66	-2.02

Notes: This table reports the economy in two scenarios: the economy without InnoCom program (column 1), and the economy with InnoCom program (column 2). W_{SCE}, $W_{reassignment}$ and W_{NCE} are defined as equation (14). All numbers are in billion RMB, except the average x has not unit.

Table 9: Impacts of Alternative Subsidy Policies

	(1) Only Inhouse patents $\rho = 0.6$	(2) Subsidize all in 8 ind. $\rho = 0.6$	(3) Only Inhouse patents with a fixed budget	(4) Subsidize all in 8 ind. with a fixed budget
Subsidy	2.75	12.88	3.40	3.40
Ave. x	3.45%	1.81%	3.53%	2.60%
(a) Industry Profit (aggregate prod):	364.10	364.20	365.74	364.04
(b) W_{SCE} ((b.1)+(b.2))	-0.49	-0.48	-0.89	0.63
(b.1) SCE innovation val.	0.06	0.06	-0.21	0.77
(b.2) $-\tau TS^{self}$	-0.55	-0.54	-0.68	-0.13
(c) $W_{reassignment}$	0.01	-0.12	0.01	-0.02
(d) W_{NCE} ((d.1)+(d.2)+(d.3))	2.35	-3.13	2.35	1.31
(d.1) NCE innovation val.	2.35	-0.92	2.35	1.85
(d.2) $-\tau TS^{T}$	0.00	-0.06	0.00	-0.01
(d.3) $-\tau TS^{NCE}$	0.00	-2.15	0.00	-0.54
Welfare ((a)+(b)+(c)+(d))	365.97	360.47	366.26	365.96

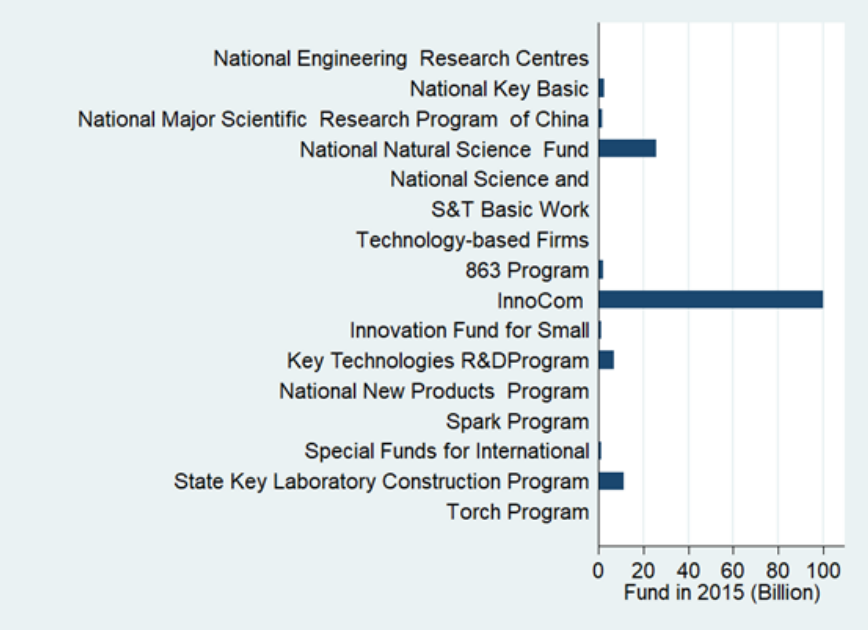
Notes: This table reports the economy in 4 different policies: only subsidizing in-house patents with $\rho = 0.6$ (column 1), subsidizing all firms from 8 InnoCom industries with $\rho = 0.6$ (column 2), only subsidizing in-house patents with a fixed fiscal budget (column 3) and subsidizing all firms from 8 InnoCom industries with a fixed fiscal budget (column 4) . W_{SCE}, $W_{reassignment}$ and W_{NCE} are defined as equation (14). All numbers are in billion RMB, except the average x has not unit.

Table 10: Optimal Subsidy Policies

	(1) Optimal subsidy wo. SEP. patents quality $\rho = 0.001$	(2) Optimal subsidy if SEP. patents $\rho_H = 0.48$, $\rho_L = 0$	(3) Optimal sub. if only SEP in-house patents quality $\rho_H = 0.62$, $\rho_L = 0$
Subsidy	0.00	1.03	0.90
Ave. x	4.30%	4.05%	5.20%
(a) Industry Profit (aggregate prod):	364.10	365.42	365.41
(b) W_{SCE} ((b.1)+(b.2)) W_{direct}	0.88	0.55	0.51
(b.1) SCE innovation val.	0.04	0.88	0.73
(b.2) $-\tau TS^{self}$	-0.55	0.00	-0.18
(c) $W_{reassignment}$	0.01	-0.01	0.01
(d) W_{NCE} ((d.1)+(d.2))	2.35	2.30	2.35
(d.1) NCE innovation val.	2.35	-0.91	2.35
(d.2) $-\tau TS^{T}$	0.00	-0.02	-0.02
Welfare ((a)+(b)+(c)+(d))	367.45	368.25	368.33

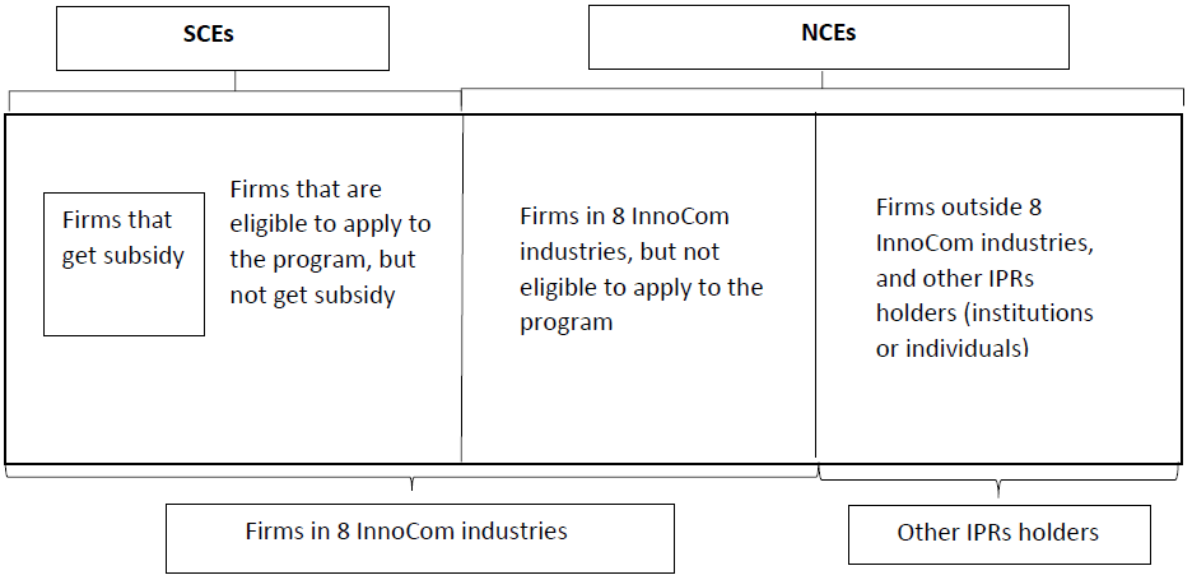
Notes: This table reports the economy in 3 different policies. Column 1 assumes that the bureaucrat cannot tell patents quality, and search ρ to maximize welfare. Column 2 assumes that the bureaucrat can tell patents quality, and search subsidy intensity for high and low quality patents ρ_H and ρ_L to maximize welfare. Column 3 assumes that the bureaucrat can tell patents quality but does not count purchased patents for subsidy, then search subsidy intensity for high and low quality in-house patents. W_{SCE}, $W_{reassignment}$ and W_{NCE} are defined as equation (14). All numbers are in billion RMB, except the average x has not unit.

Figure 1: The Subsidies of Various Pro-innovation Policies by Chinese Central Government



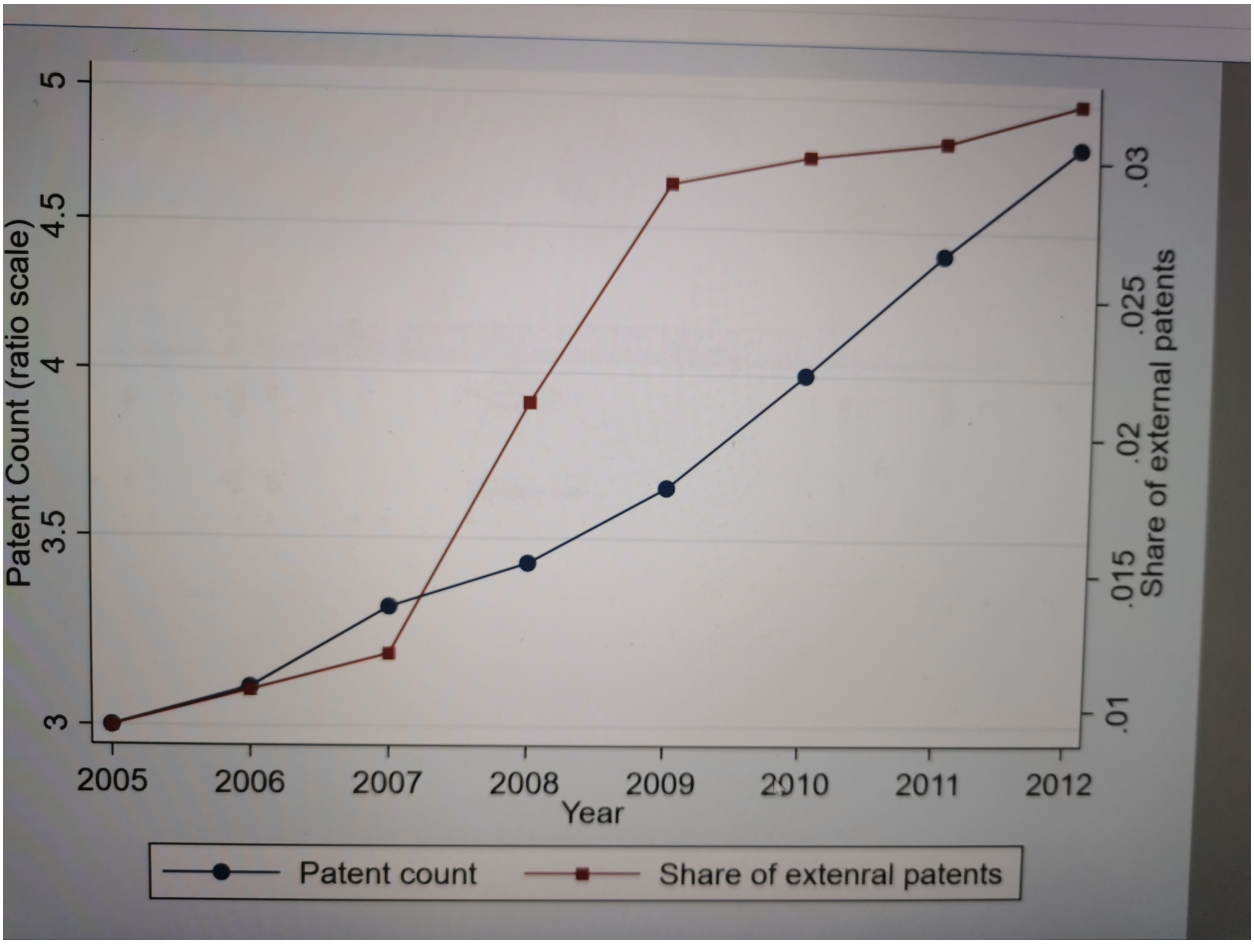
Notes: This figure shows subsidies of various major pro-innovation policies supported by by Chinese Central Government. Source: China Yearbook of Science and Technology 2015.

Figure 2: The Data Structure



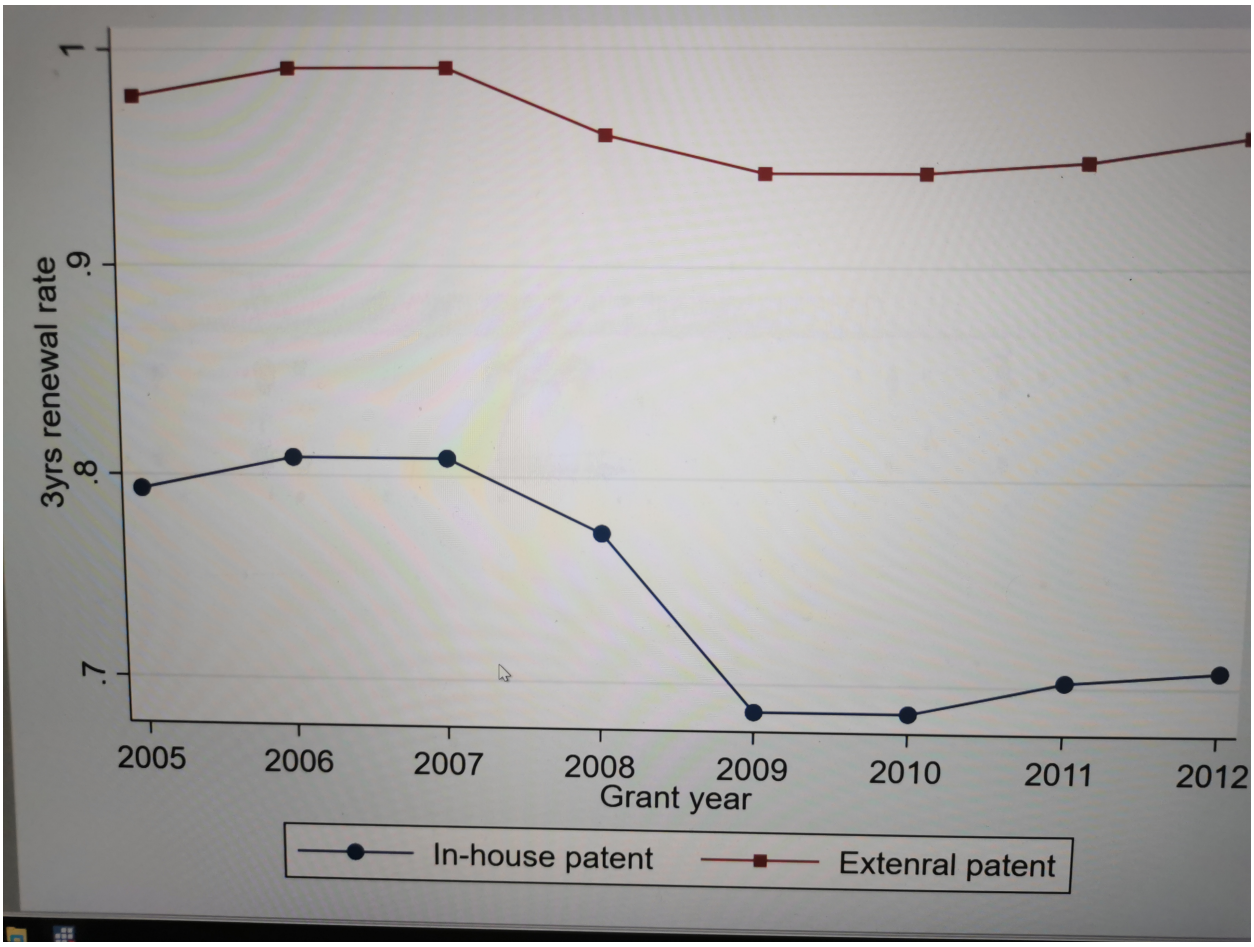
Notes: This figure shows the data structure of the sample.

Figure 3: Granted Patents and Traded Patents per firm from 2005-2012



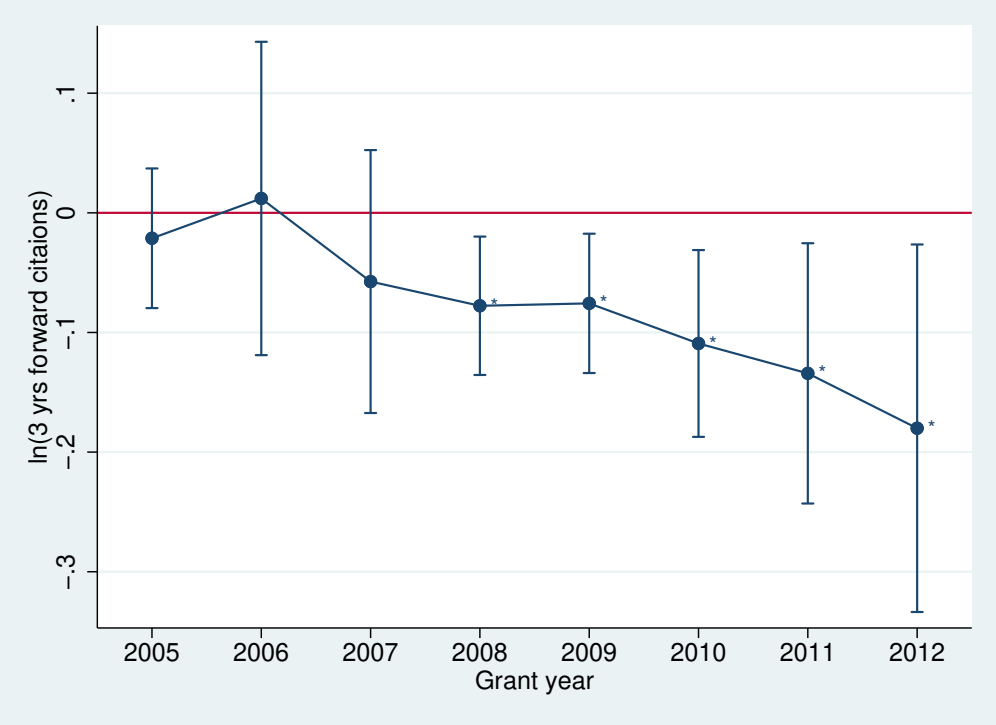
Notes: This figure shows the number of new obtained patents and share of external patents per firm from 2005-2012.

Figure 4: 3Yrs Renewal Rates of Internal and External Patents from 2005-2012



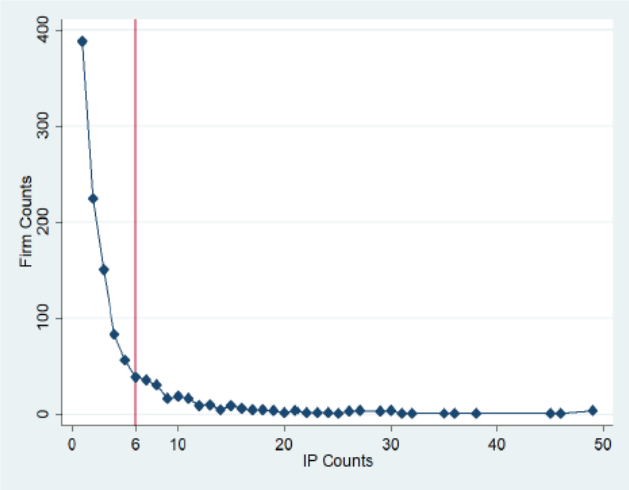
Notes: This figure shows the average 3-years renewal rates of internal and external patents granted within 2005-2012. External(internal) patent is defined as a patent that has (not)been traded within 3 years after granted.

Figure 5: 3 Years Forward Citations of Patents

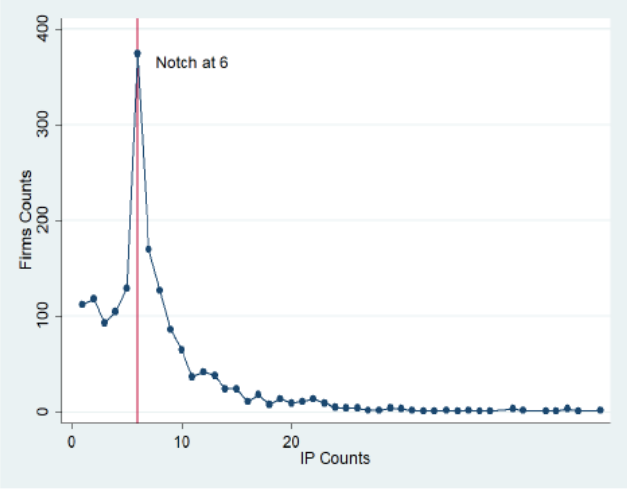


Notes: This figure shows the average ln(3 years forward citations) of patents granted from 2005 to 2012. The citation in 2004 is normalized to 0. Capped spikes represent 90% confidence intervals.

Figure 6: The IPRs Holding Distribution



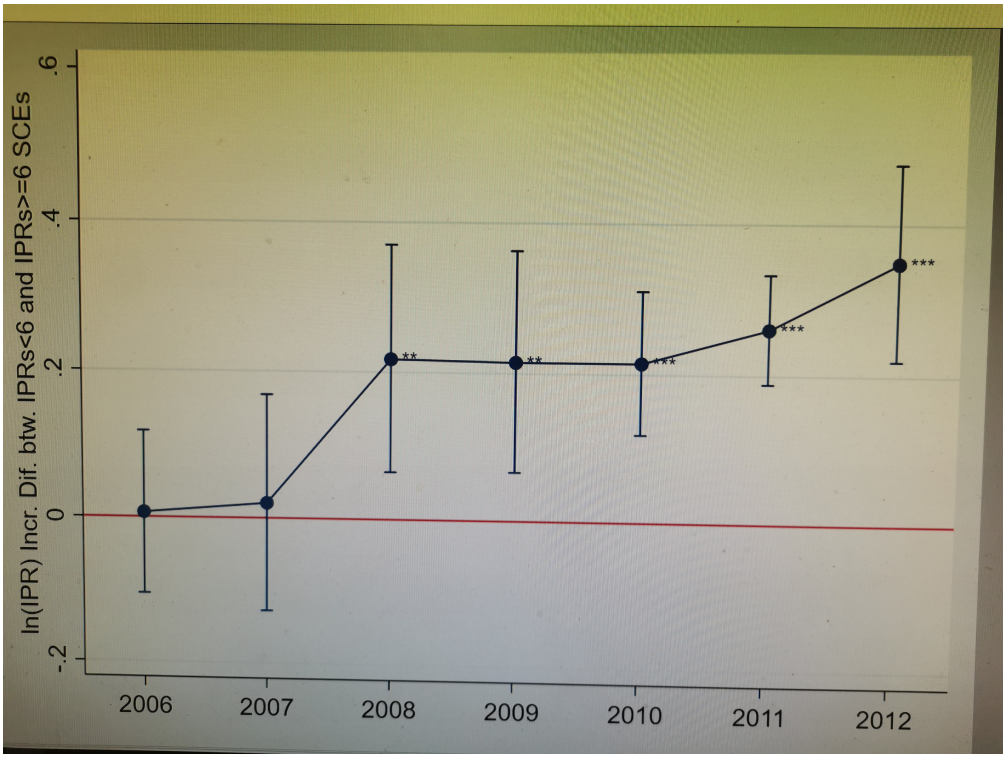
Year 2007



Year 2008

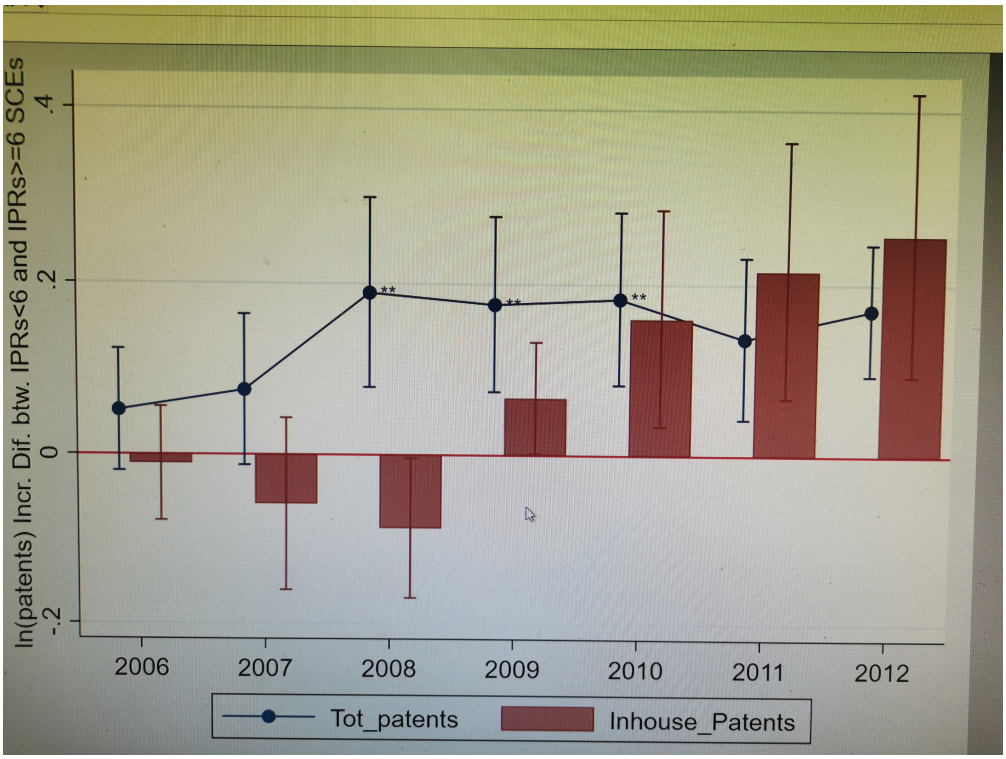
Notes: This figure shows the IPRs (patents and software copyrights) holding distributions of the subsidized firms in Beijing in year 2007 and 2008.

Figure 7: New IPRs of SCEs with IPRs<6 over Years



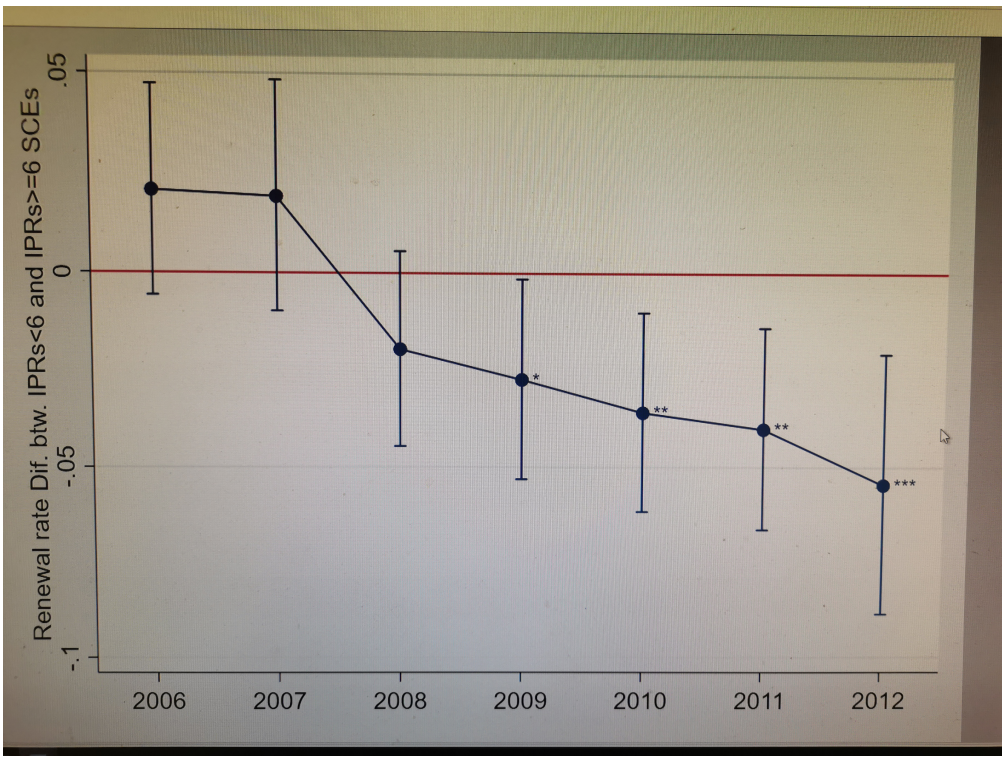
Notes: This figure shows estimates of α_3 in equation (1) by years. The circles indicate point estimates of α_3. New IPRs of SCEs with IPRs$\geq$6 is normalized to 0 in each year. Capped spikes represent 90% confidence intervals.

Figure 8: New (in-house) Patents of SCEs with IPRs<6 over Years



Notes: This figure shows estimates of α_3 in equation (1) by years using $ln(patents)$ (circle) and ln(in-house patents) (red bar) as dependent variables. New patents of SCEs with IPRs$\geq$6 is normalized to 0 in each year. Capped spikes represent 90% confidence intervals.

Figure 9: 3Yrs Renewal Rates of SCEs with IPRs<6 over Years



Notes: This figure shows estimates of β_3 in equation (2) by years. Renewal rates of SCEs with IPRs$\geq$6 is normalized to 0 in each year. Capped spikes represent 90% confidence intervals.

Figure 10: Timing

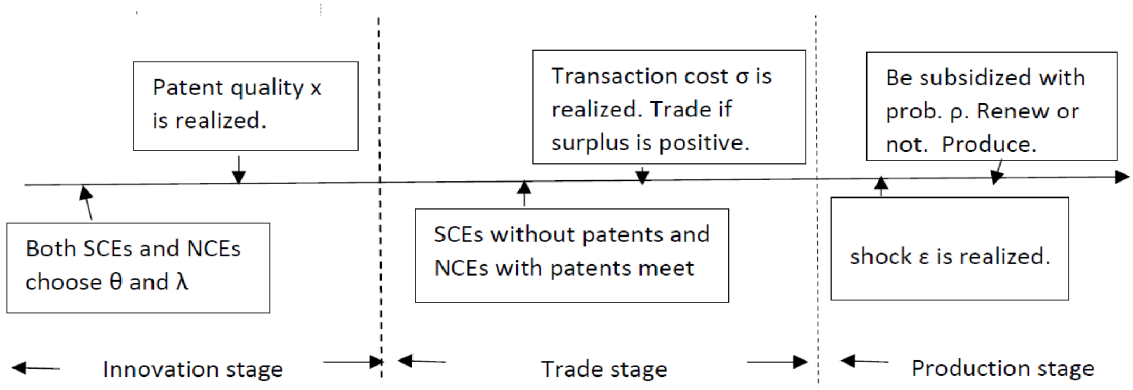
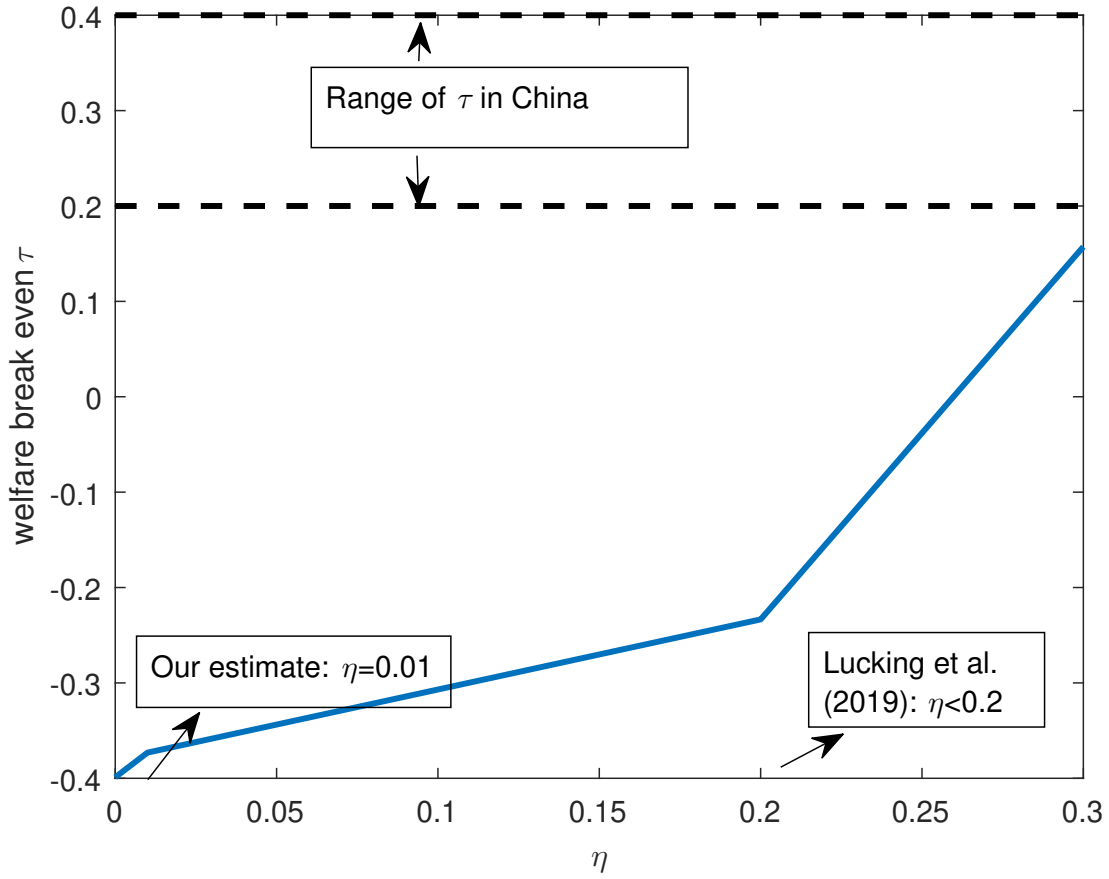


Figure 11: Combinations of social cost of public funding η and technological spillover parameter τ that make InnoCom Program Welfare Neutral



Notes: This figure shows the combinations of knowledge externality parameter η and shadow value of public funding τ that makes the policy welfare neutral (the welfare with and without the policy after 2008 are the same).

Online Appendix (not for publication in print)

A Details of the InnoCom Program

This section has two parts. In the first part, we explains the details on how the InnoCom program evaluates firms. In the second part, we compares the program with other innovation subsidy programs in China.

Table A1 lists the conditions that the firm must satisfy in order to apply for the Innocom program. As we can see, the pre-requirements are based on the R&D-to-sales ratio, the sales of high-tech products, the share of R&D workers, and the number of IP rights (IPRs).

After the application, the local government evaluates the firms based on four parts:the intellectual property rights, the ability to manage R&D, S&T commercialization, and the firm growth. The full marks in the 4 parts are 30, 30, 20, 20 respectively.

We explain the grading criteria of holding intellectual property rights in the first column of Table A2. A noteworthy point is the grading scheme of the IPRs. The firm gets an "A" if they have 6 or more IPRs. Here we emphasize two important points. First, the subsidy program only counts the number of IPRs but does not take into account the quality of the IPRs. Second, the firms do not get any extra points if they have more than 6 IPRs.

We explain the grading criteria of the last three categories in Table A3. We can see that for each category, it has 6 levels (A to F). Different levels represent different points the firm can get in that category. The total points of the three categories are 70.

Moreover, when the program was first introduced in 2008, the program recognized two ways of holding an IPR: the firm can either be the owner of the IPR (either innovate in-house or purchase from outside) or can hold the IPR under an exclusive license. In other words, for those patents which the firm borrow from others, the program still count them.

The InnoCom program is the largest pro-innovation program in China. Table A4 list budgets of various pro-innovation programs in China. As we can see, InnoCom program's budget significantly dominates other programs.

Table **??** shows the coverage of the InnoCom program in our data set. On average, the program each year provides a subsidy to more than 5,800 firms, about 68% of all SCEs, or 21% of all firms in the eight industries. The subsidy (tax reduction) is about 0.62 million RMB per firm per year, or 1.86 million RMB over three years.

Table A1: Necessary Requirements of the Innocom Program

R&D Intensity	6% if sales $<$ 50 millions of RMB 4% if sales $>$ 50 & sales $<$ 200 millions of RMB 3% if sales $>$ 200 millions of RMB
Sales of High Tech Products	60% of total sales
Workers with College Degree	30% of workforce
R&D Workers	10% of workforce
IP right	Necessary

Table A2: Grading Scheme of the IPR Counts

Letter Grade	Points	Criteria
A.	30-24	6 or more IPRs (or at least 1 invention)
B.	24-18	5 IPRs
C.	18-12	4 IPRs
D.	12-6	3 IPRs
E.	6-0	1-2 IPRs
Notes: Both purchased and self-developed IPRs are counted.		

Notes: This table explains the grading scheme of the IPR counts in the InnoCom program.

Table A3: The Grading Scheme of the Innocom Program

Category	Grading Criteria
Ability to transform research projects to business (30 points)	A. Above 4 items (30-24 points) B. 3-4 items (30-24 points) C. 2-3 items (18-12 points) D. 1-2 items (12-6 points) E. 1 item (0-6 points) F. 0 item (0 point)
Research management ability (20 points)	(1) Make research proposals (2) Have R&D expenditure accounting system (3) Co-operate with research institutions (4) Have independent research departments (5) R&D workers' performance evaluation system A. 5 items (16-20 points) B. 4 items (12-16 points) C. 3 items (8-12 points) D. 2 items (4-8 points) E. 1 item (0-4 points) F. 0 item (0 point)
Firm growth (20 points)	Asset growth (10 points) A. $\geq$35% (8-10 points) B. $\geq$25% (6-8 points) C. $\geq$15% (4-6 points) D. $\geq$5% (2-4 points) E. $<$ 5% (0-2 points) F. $\leq$ 0 (0 points) Sales growth (10 points) A. $\geq$35% (8-10 points) B. $\geq$25% (6-8 points C. $\geq$15% (4-6 points) D. $\geq$5% (2-4 points) E. $<$5% (0-2 points) F. $\leq$ 0 (0 points)

Table A4: Budgets of Various Pro-Innovation Policies in China

Programs	Program names in Chinese	Fund in 2015 (Billion)
InnoCom	高新科技企业认定	100
National Natural Science Fund	国家自然科学基金	25.8
State Key Laboratory Construction Program	国家重点实验室	11.5
Key Technologies R&D Program	科技支撑计划	7.0
National Key Basic Research Program of China	国家重点基础研究发展计划（973计划）	2.7
863 Program	863计划	2.0
National Major Scientific Research Program of China	国家重大科学研究计划	1.7
Special Funds for International Technology Cooperation	国际科技合作与交流专项经费	1.4
Innovation Fund for Small Technology-based Firms	科技型中小企业技术创新基金	1.1
National Science and Technology Infrastructure Program	科技基础条件平台专项	0.3
S&T Basic Work	科技基础性工作专项	0.2
Torch Program	火炬计划	0.2
Spark Program	星火计划	0.2
National Engineering Research Centres	国家工程技术	0.1

Table A5: Coverage of InnoCom Program

Year	No. of new Innocom firms	%. in SCEs	% in 8 Innocom Ind.	Sub. per firm-year
2008	2,470	52%	5%	-
2009	5,167	59%	16%	0.58
2010	6,401	67%	20%	0.53
2011	7,204	72%	33%	0.74
Average	5,860	68%	21%	0.62

Notes: This table shows the number of new InnoCom firms from 2008-2011, and the share of subsidized firms in all SCEs and 8 high-tech industries in our data set. The last column shows the annual subsidy (tax return) per InnoCom firm, which is computed using the State Administration Tax Data. The tax information of InnoCom firms in 2008 is missing.

B Knowledge spillover is positive but modest

The main motivation of the InnoCom program is to encourage more innovations, hence may increase the aggregate productivity through the knowledge externality. To gauge the welfare effect of the InnoCom program, we need to know to what extent the knowledge externality depends on the quality and quantity of patents. We estimate the knowledge externality as follows.

Let i and j denote two industries. Denote N_{it} as the total patents (cumulative) in industry i up to year t, and r_{it} as the average renewal rate (survival rate of patents three years after granted) of the industry i. Define K_{it} as the measure of total patents with which industry i interacts in the aggregate productivity. We call K_{it} as the "knowledge capital" facing by i. Specifically, we distinguish the knowledge capital from the same sector K_{it}^{within}, and from other sectors K_{it}^{other},

$$K_{it}^{within} = d_{ii} N_{it} r_{it},\ K_{it}^{other} = \sum_{j \neq i} d_{ij} N_{jt} r_{jt} \tag{19}$$

where d_{ij} is the knowledge distance between industry i and j, which is measured as the share of patent citations between industry i and j within all patent citations. The above functions imply that high quality patents (high renewal rates) contribute more to the knowledge capital. Meanwhile, the knowledge externality is greater between two industries that cite each other more frequently.

Consider a firm f in industry i_f. We then estimate the following equation

$$\ln \pi_{ft} = \eta_1 \ln K_{i_f,t}^{within} + \eta_2 \ln K_{i_f,t}^{other} + \mu_f + \mu_t + error \tag{20}$$

where π_{ft} is firm f's labor productivity (profit/workers),$K_{i_f,t}^{within}$ and $K_{i_f,t}^{other}$ are the knowledge capital facing by firm f, and μ_f and μ_t are the firm and time fixed effects. η_1 and η_2 measure

the knowledge externality from the same sector and other sectors.

Firm f's own innovation may change K. So we only focus on firms without any patents. To exclude the impact of InnoCom program, we focus on 2000-2007, a sample one year before the InnoCom program.[39]

Some unobserved shocks may affect π_{ft} and industry level innovations at the same time. So we instrument $K_{i_f,t}^{within}$ and $K_{i_f,t}^{other}$ as

$$IV_{it}^{within} = d_{ii}\frac{Patent_{i0}}{TotPatent_0}S_t,\ IV_{it}^{other} = \sum_{j\neq i} d_{ij}\frac{Patent_{j0}}{TotPatent_0}S_t \tag{21}$$

where $Patent_{i0}$ is the patent counts of industry i in 1998, and $TotPatent_0$ is the total patent counts in 1998. S_t is the total subsidy to innovations from Chinese central government. The assumption is that the total innovation subsidy changes patent counts in different industries proportional to the initial patent share across industries. Meanwhile, the total subsidy does not directly change the productivity of firms without any patents.

Table A6 reports the estimation results of η. In the first column, the OLS estimates suggest that when the industry's total patents increase by 1%, the labor productivity of a firm without patents increases by 0.052%. However, if other industry's patents increase by 1%, the firm's labor productivity drops by 0.102%. In the second column, we instrument K and find that η_1 decreases to 0.01, which means that the knowledge externality within the same sector is very small. Meanwhile, the knowledge externality across sectors is slightly negative (-0.012), although not significantly away from 0.[40]

In the third column, we change the definitions of K by simply counting patent numbers without adjusted by renewal rates. Comparing to column 2, both η_1 and η_2 decrease, and

[39]We use Annual Survey of Chinese Manufacture Enterprises dataset since this data covers firms financial information up to 2009. However, in the tax records administrative data, the observation starts from 2007.

[40]In the first stage, we find the F statistics is over 2,000.

the knowledge externality within the sector becomes not significant. This result suggests that the productivity benefits more from other firms' high quality patents.

Are the knowledge externality in InnoCom industries different from other industries? This question is important when we discuss the welfare of the InnoCom program. In the fourth column, we allow η to be different for InnoCom industries, by introducing a dummy D which indicates whether the industry is targeted by the InnoCom program. The coefficient before $K^{within} \times D_{InnoCom}$ and $K^{other} \times D_{InnoCom}$ reflect the difference of η_1 and η_2 between InnoCom industries and other industries. As we see, we do not detect any significant difference.

Since the patent quality declines after the InnoCom program was implemented, will η of InnoCom industries decrease after 2008? We then restrict the sample to 2008-2009, and estimate a similar equation as column 4. The result is shown in column 5 of Table A6. Comparing with column 4, in terms of non-InnoCom industries, the knowledge externality within the sector is barely unchanged (0.015), and the knowledge externality across sectors decreases but still not significant away from 0. However, the knowledge externality of InnoCom industries decrease both for $\ln K^{within}$ and $\ln K^{others}$, although they are not significant. One reason for any insignificant decline may be that we adjust patent count by renewal rates, which may have captured patents quality decline.

So we conjecture that if K is not adjusted by renewal rates, the externality of InnoCom industries would drop significantly after 2008. In column 6 and 7, we estimate equations similar as column 4 and 5, but do not adjust K by renewal rates. (The sample is before 2008 in column 6, and after 2008 in column 7.) First, comparing column 6 to 4, η_1 slightly declines, which may suggest that high quality patents contribute more to the within sector knowledge externality. Second, we again do not detect a significant difference in η between InnoCom industries and other industries before the InnoCom subsidy. After 2008, the externality of other sectors are barely not changed (comparing column 7 and 6), but the within sector

externality of InnoCom industries significantly decreases. Overall, column 7 suggests that if the patent count increases by 1% in the InnoCom industry after 2008, the labor productivity of other firms in the same industry without patents would decline by 0.004% (0.011-0.015). This result confirms our conjecture: InnoCom program pushes down the patents quality, hence more patents (without adjusting the quality) do not contribute too much to other firms' productivity.

To sum up, a small but positive knowledge externality exists within the sector, but we do not find any significant knowledge externality across sectors. With US data, Lucking et al. (2019) use R&D expenditure to measure K and find that η from 0 to 0.2. Our estimates are significant smaller than theirs. These may be either because the knowledge externality within China is smaller or because we measure K by patent counts. After an innovation is patented, the knowledge spillover would decrease due to the patent protection.

Table A6: Knowledge Externality of Patents

	(1) OLS	(2) IV	(3) IV raw K	(4) IV InnoCom Ind.	(5) IV InnoCom Ind. Post-2008	(6) IV InnoCom Ind. raw K	(7) IV InnoCom Ind. raw K / Post-2008
$\ln K^{within}$	0.052***	0.010*	0.009	0.011*	0.015*	0.01	0.011
	-0.012	-0.006	-0.008	-0.007	-0.008	-0.008	-0.013
$\ln K^{other}$	-0.102***	-0.012	-0.013	-0.011	-0.024	-0.013	-0.009
	-0.025	-0.016	-0.017	-0.019	-0.017	-0.019	-0.026
$\ln K^{within} \times D_{InnoCom}$				-0.005	-0.013	-0.004	-0.015*
				-0.008	-0.009	-0.008	-0.009
$\ln K^{other} \times D_{InnoCom}$				0.008	0.003	0.007	0.004
				-0.009	-0.009	-0.009	-0.009
Firm FE	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y
IV		Y	Y	Y	Y	Y	Y
K: Renewal rate adj.	Y	Y		Y	Y		
Sample after 2008					Y		Y
KP Wald F stat		2175.7	3017.11	5929.45	1500	4594.17	1400.04
Obs.	1,120,443	1,120,443	1,120,443	1,120,443	373,074	1,120,443	373,074
Adj. R2	0.65	0.65	0.65	0.65	0.67	0.65	0.67

Notes: This table reports the estimates of knowledge spillover within and across sectors (equation (20)). The dependent variable is the log of labor productivity (profit/worker) of a firm without patent. The $D_{InnoCom} = 1$ if the firm is in an InnoCom industry and 0 otherwise. In column (3), K is not adjusted by the renewal rate. The IV of column (2) to (7) is defined in equation (21). "KP Wald F stat" refers to Kleibergen-Paap Wald F-statistic in the first stage estimation. Standard errors are reported in the parentheses and clustered at the firm-year level. *** p<0.01, ** p<0.05, * p<0.1.

C Numerical Details

We assume that x follows a Bernoulli distribution: $x = x_H$ with probability λ and $x = x_L$ with probability $1-\lambda$. And $x_H > x_L$. Furthermore we assume that $C = \frac{v_0}{2}(\lambda\theta)^2 + \frac{v_1}{2}\theta^2$. Then the optimization of the SCE is

$$\begin{aligned} w_S &= \max_{0\leq\lambda_S(z)\leq 1, 0\leq\theta_S(z)\leq 1} \Delta(z)\lambda_S(z)\theta_S(z) + B(q_S,\lambda_N)\theta_S(z) + \frac{q_S}{2}[\lambda_N S^+(z,x_H,\rho) + \\ &\quad (1-\lambda_N)S^+(z,x_L,\rho)] - \frac{v_{0S}}{2}(\lambda_S(z)\theta_S(z))^2 - \frac{v_{1S}}{2}\theta_S^2(z) \end{aligned}$$

where $\Delta(z) = V(z,x_H) - V(z,x_L)$ and $B(q_S,\lambda_N) = V^S(z,x_L) + \rho T(z) - \frac{q_S}{2}[\lambda_N S^+(z,x_H,\rho) + (1-\lambda_N)S^+(z,x_L,\rho)$.

The optimal conditions yield that

$$\theta_S(z) = \max(\min(\frac{B(q_S,\lambda_N)}{v_{1S}}, 1), 0)$$

$$\lambda_S(z) = \max(\min(\frac{\Delta(z)}{v_{0S}\theta_S(z)}, 1), 0) \text{ if } \theta_S > 0; \text{ otherwise } \lambda_S = 0$$

Similarly, the optimization of the NCE is

$$w_N = \max_{0\leq\lambda_N\leq 1, 0\leq\theta_N\leq 1} D(q_N,\theta_S)\lambda_N\theta_N + E(q_N,\theta_S)\theta_N - \frac{v_{0N}}{2}(\lambda_N(z)\theta_N(z))^2 - \frac{v_{1N}}{2}\theta_N^2(z)$$

where $D(q_N,\theta_S) = V(z_N,x_H) - V(z_N,x_L) + \frac{q_N}{2}\sum_z \alpha(z)[S^+(z,x_H,\rho) - S^+(z,x_L,\rho)]$, and $E(q_N,\theta_S) = V(z_N,x_L) + \frac{q_N}{2}\sum_z \alpha(z)S^+(z,x_L,\rho)$. And $\alpha(z) = \frac{(1-\theta_S(z))p(z)}{\sum_z(1-\theta_S(z))p(z)}$ is the share of SCEs with productivity z that are buyers.

Then the optimal conditions of NCE yield

$$\theta_N = \max\left(\min\left(\frac{E(q_N,\theta_S)}{v_{1N}}, 1\right), 0\right)$$

$$\lambda_N = \max\left(\min\left(\frac{D\left(q_N, \theta_S\right)}{v_{0N}\theta_N}, 1\right), 0\right) \text{ if } \theta_N > 0; \text{ otherwise } \lambda_N = 0$$

The free entry condition of NCE can be written as

$$D\left(q_N, \theta_S\right)\lambda_N\theta_N + E\left(q_N, \theta_S\right)\theta_N = C_N\left(\lambda_N, \theta_N\right) + \kappa \tag{22}$$

We can see that an increase of ρ will increase B and E. So $\theta_S\left(z\right), \theta_N$ would increase, and $\lambda_S\left(z\right)$ will decrease. The change of λ_N depends on D. Generally, when ρ increases, D may decrease. So λ_N would decrease.

We can solve the model as follows. For each period, guess δ. Then solve q_S and q_N. Then guess λ_N, solve $\lambda_S\left(z\right)$ and $\theta_S\left(z\right)$. Then we can solve E and D, and we can update the guess λ_N from NCE's optimality policy. Then we can check the NCE's free entry condition to pin down δ. In the end, we need verify the guess of the aggregate productivity.

D More tables

Table A7: Decomposition of the Annual Patent Trade Growth

Seller \ Buyer	SCEs IPRs<6	SCEs IPRs≥6	NCEs
	2006-2007		
SCEs IPR<6	0.080	-0.667	-0.238
SCEs IPR≥6	-0.338	0.091	-0.093
NCEs	-0.222	-0.355	0.164
	2007-2012		
SCEs IPR<6	0.108	-0.002	-0.017
SCEs IPR≥6	0.055	0.016	0.091
NCEs	0.151	-0.001	0.331

Notes: This table decomposes the annual patent trade growth into 9 categories based on buyers' and sellers' characteristics.

Table A8: Summary Statistics of the SCEs and NCEs before and after 2008

	2005-2007			2008-2012		
	SCEs IPR< 6	SCEs IPR ≥ 6	NCEs	SCEs IPR< 6	SCEs IPR ≥ 6	NCEs
Per-firm:						
Internal patents	0.99	5.26	2.56	3.21	6.83	2.79
External patents	0.69	1.40	0.03	1.37	1.42	0.02
3Yrs renewal rate of:						
In-house. patents	0.91	0.92	0.77	0.83	0.88	0.64
External patents	0.99	0.95	0.96	0.97	0.91	0.89
$\frac{ln(\text{labor prod})}{\text{patents}}$	0.07	0.04	0.02	-0.05	0.002	-0.01

Notes: This table shows the summary statistics of SCEs and NCEs before and after 2008 (balanced panel).

Table A9: Effects of InnoCom on Quality of Patents Produced by NCEs

	(1) $Renew_{it}$	(2) $Renew_{it}$	(3) $Renew_{it}$
$Psale_{it-1}^{SCE} \times (t \geq$	-0.066***	-0.071	-0.070***
2008)	-0.018	-0.041	-0.02
$Psale_{it-1}^{NCE} \times (t \geq$	-0.019	-0.02	-0.027
2008)	-0.013	-0.013	-0.023
$Psale_{it-1}^{SCE,IPR<6} \times$		-0.075**	
$(t \geq 2008)$		-0.026	
$Psale_{it-1}^{SCE}, Psale_{it-1}^{NCE}$	Y	Y	Y
$Psale_{it-1}^{SCE,IPR<6}$		Y	
Firm/Year FEs	Y	Y	Y
Individual NCEs			Y
Obs.	22,486	22,486	12,987
Adj. R2	0.35	0.35	0.34

Notes: This table presents the estimation results of renewal rates of new patents (equation (**??**)) of NCEs. $PSale_{it-1}^{SCE}$, $PSale_{it-1}^{NCE}$ and $PSale_{it-1}^{SCE,IPR<6}$ are the number of patents sold to SCEs, NCEs and SCEs with IPRs fewer than 6, respectively. Standard errors are reported in the parentheses and clustered at the firm-year level. *** p<0.01, ** p<0.05, * p<0.1.