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## Product-level evidence of the determinants and impacts of public agricultural research: Panel analysis of plant patent in Japan

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### Abstract

The public sector is an important source of agricultural research as many of the agricultural producers are individual farmers who cannot bear the cost of research and development. Public institutes for experimentation and research called *Kosetsushi* help producers in agriculture and manufacturing improve productivity through technology transfer activities, thereby constituting an important component of regional innovation systems in Japan. This study establishes panel data of agricultural research input and output (new variety of a plant) by *Kosetsushi* and examines whether their research activities are responsive to local needs and which type of research effort is conducive to the promotion of agricultural product innovation measured as registration of new varieties. Estimation results reveal significant variations across plants in the impacts of agricultural clusters on research on that plant. The impact of research on plant breeding on product innovation also varies across plants. Policy implications of the major findings are discussed.

### Introduction

The public sector is an important source of agricultural research for several reasons. Public institutes for experimentation and research called *Kosetsushi* constitute an important component of regional innovation systems in Japan. *Kosetsushi* were initially established in the late 19th century in agriculture, textiles, and brewing (e.g., sake, soy sauce), and then gradually developed in manufacturing (Fukugawa and Goto 2016). *Kosetsushi* help small and medium-sized enterprises (SMEs) and individual farmers improve productivity through various technology transfer activities. They play three key roles in regional innovation systems. First, they diffuse technological knowledge through various routes, such as technical consultation and seminars for the introduction of standards. Second, they conduct their own research, patent inventions, and license patents mainly to local SMEs. Third, they act as a catalyst for local SMEs to develop innovative networks to external sources of knowledge, such as universities. Collectively, *Kosetsushi* act as public innovation intermediary to promote knowledge creation and dissemination in regional innovation systems.

Regardless distinctive features in terms of regional embeddedness and research intensity, little has been known about structure and impact of research activities of agricultural *Kosetsushi* in regional innovation systems. This study aims to address the research gap by establishing panel data of research activities and research outcomes (i.e., new variety of a plant) by agricultural *Kosetsushi*. This study examines the following research questions. First, is their allocation of research effort responsive to local needs for research? Second, which research effort is

efficiently transformed to agricultural product innovations? Third, is there a product-level difference in the impact of research effort?

### **Analytical Framework**

#### *Measuring responsiveness to local needs*

If local farmers concentrate on specific agricultural production, they are likely to face problems unique to the product. Then, it is predicted that agricultural *Kosetsushi* in the region allocate research resources according to agricultural production clusters in that region so that they could provide solutions to the local problems more efficiently. In light of this, the present study measures local research needs by location quotient and examines the change in research effort allocated to a specific product in relation to that in location quotient of the product. The location quotient is defined as  $LQ_{ij} = (A_{ij}/B_j)/(A_i/B)$ .  $A_{ij}$  is the agricultural production of a plant  $i$  ( $i=1\dots 10$ : the number of plants examined), and in a prefecture  $j$  ( $j=1\dots 47$ : the number of prefectures).  $B_j$  is the agricultural production in  $j$ .  $A_i$  is the agricultural production of  $i$ .  $B$  is the agricultural production in Japan.

The more specialized the production in a specific plant, the greater the location quotient of that plant. For instance, if the agricultural production in a region is concentrated even more in vegetable than the population mean, the location quotient would be much greater than one in vegetable. And if such a concentration in vegetable is more intensive than that in any other prefecture, it can be said that farmers in the region are the most likely to have research needs related to vegetable (e.g., development of new variety invulnerable to specific pest damage). If regional innovation policy is designed and implemented so as to fit local research needs, then agricultural *Kosetsushi* in the region would allocate more research resources to vegetable. It should be noted that the location quotient is measured by plant and by prefecture while econometric analysis is conducted by product. Therefore, what is analyzed in this study is the relationship between regional variation in production concentration of a product and that in effort allocated to research on the product.

#### *Measuring impact of agricultural research on product innovation at the product level*

Agricultural *Kosetsushi* engage in various types of research and generate various types of outcomes in the form of scientific articles, technological standards, and workshops for education and training, each of which is conducive to the productivity improvement of local farmers, and thus considered as innovation. New variety of a plant registered by agricultural *Kosetsushi* is a typical example of product innovation while manual of pest control is considered as that of process innovation. This study measures the impact of agricultural research on product innovation as elasticity (percentage change in research output in relation to percentage change in research input). In econometric analysis, this is estimated by regressing log of research effort against log of product innovation.

Previous innovation surveys in the manufacturing sector show that, in most of the industries, secrecy and a first-mover advantage are more important as appropriation methods (the most profitable way to recoup innovative investment) than legal methods, such as patents (Cohen et al. 2000; Nagaoka and Walsh 2009). In agriculture, the legal protection of product innovation corresponds to the registration of new variety of plant. The public sector is an important source of agricultural research, and thus agricultural product innovations. Therefore, the public sector appears to be the main source of agricultural patenting as well. Previous innovation surveys in the manufacturing sector found a significant industry-level variation in the effectiveness of patent. Similarly, there is a significant product-level variation in the effectiveness of legal protection of agricultural product innovation. For instance, availability of the first filial hybrid

makes it unnecessary for innovators to seek legal protection of their inventions because farmers have to buy seeds every season they start growing the plant. This is quite true of vegetable production in Japan, but not applicable to rice, which affects the prevalence of legal protection as appropriation method across agricultural products. In light of this, the present study analyzes the impact of agricultural research on agricultural product innovation at the product level.

## Method

### Model

This study estimates the two-way error components model described as follows.

$$R_{plant}_{ipt} = \alpha_1 + \beta_1 Cluster_{plant}_{ipt} + u_{ip} + v_{it} + \varepsilon_{ipt} \quad (1);$$

$$\ln Y_{ipt} = \alpha_2 + \beta_2 \ln R_{field}_{ipt-q} + u_{ip} + v_{it} + \varepsilon_{ipt} \quad (2).$$

$R_{plant}$  denotes the number of researchers at agricultural *Kosetsushi* allocated to research on a specific plant  $i$ .  $Cluster_{plant}$  denotes location quotients of a specific plant in a prefecture (local unit of governance in Japan)  $p$  where agricultural *Kosetsushi* are located.  $Y$  denotes the number of new varieties of a plant registered by agricultural *Kosetsushi*.  $R_{field}$  denotes the number of researchers allocated to research on a specific field, weighted by the proportion of  $R_{plant}$  to the number of researchers. Suffix  $p$  denotes a prefecture in which agricultural *Kosetsushi* are located. Suffix  $i$  denotes a type of a plant being developed (i.e., rice, flower, fruit, and vegetable). Suffix  $t$  denotes the year of registration of the new variety of a plant. Suffix  $q$  denotes a lag required for the research inputs to be transformed into agricultural product innovations. An error component,  $u$ , denotes time-invariant individual effects. Another error component,  $v$ , denotes time effect which represents exogenous shocks to all agricultural *Kosetsushi*, such as a change in regulation. Last,  $\varepsilon$  denotes the error term.

### Data

Information of location quotient is collected from the Agricultural Income Statistics, compiled by the Ministry of Agriculture, Forestry and Fisheries. Information of  $Y$  is collected from the Database of Seed Registration and Application, compiled by the Ministry of Agriculture, Forestry and Fisheries. The database provides information on ten plants. Only four of them (i.e., rice, flower, fruit, and vegetable) retain the sufficient number of observations for panel analysis. The balanced panel on which the present study builds is the time-series and cross-prefectural data. With regard to Equation 2, a dependent variable includes many zeros. Therefore, a random-effects Tobit regression model is used for estimation to analyze truncated data. Random effects model was selected as there is not a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood.

Information of research effort allocation is collected from the Ministry of Agriculture, Forestry and Fisheries “the Basic Survey of Agricultural *Kosetsushi*”. This survey provides two types of information on the allocation of research effort by plant and research field. The survey asked agricultural *Kosetsushi* to divide the number of researchers to fifteen research field, and nineteen agricultural outputs. In other words, the number of researchers  $R$  is described as

$R = \sum_{i=1}^{15} x_i = \sum_{j=1}^{19} y_j$  where  $x_i$  denotes the effort allocated to a research field  $i$  and  $y_j$  denotes the effort allocated to a plant  $j$ . It should be noted that  $x_i$  and  $y_j$  can be decimal even though  $R$  is natural number.

A long lag structure is distinctive feature of agricultural research. Experts suggested in interviews I conducted for the collection of background information about agricultural research and extension that  $q$  significantly varied across plants. To incorporate different lagged

structures in the regression model, I have collected information of the “development lag” between commencement and completion of research projects associated with the breeding of a specific plant. Information is collected from the Annual Report of Agricultural Experiment and Research Institutes compiled by the Ministry of Agriculture, Forestry, and Fishery. This survey shows that average development lag is ten years for rice, 6.4 years for fruit, five years for flower, and 4.9 years for vegetable. An average lag between application and registration of new varieties of a plant is 2.8 years.

## Results and Discussion

Table 5 shows estimation results of Equation 1. The results of both a random-effects model and fixed-effects model are presented. A fixed effects model is supported by the result of Hausman test for all models. Coefficients of research effort allocated to agriculture are positive and statistically significant. Coefficients of location quotient are not statistically significant for rice and flower and significantly negative for vegetable. Only fruit exhibits coefficient with a predicted sign and statistical significance. With regard to rice, positive coefficients in a random-effects model disappear when individual effects are controlled by dummy variables. This suggests that time-invariant, region-specific factors, such as natural conditions, affect a dependent variable and an independent variable in the same direction. For instance, prefectures with better water reservation tend to develop rice cluster and allow agricultural *Kosetsushi* located there to allocate more research effort to rice, which may have generated a spurious correlation between a dependent variable and an independent variable. What is striking is a negative impact of vegetable cluster on the research effort allocated to vegetable by agricultural *Kosetsushi*. One interpretation is that vegetable consists of many items and some of them are seen as an attractive commercial crop by prefectures struggling with stagnant agricultural turnover. Production of vegetable normally requires less investment into civil engineering and agricultural machineries than rice farming, which lowers entry barrier. Collectively, there may be tendencies for a prefecture with less vegetable production to allocate more research effort on that by *Kosetsushi* located in the prefecture in order to bolster agricultural production by developing a commercially successful item.

Table 5 Estimated two-way error component models: Dependent variable=research effort on a specific plant

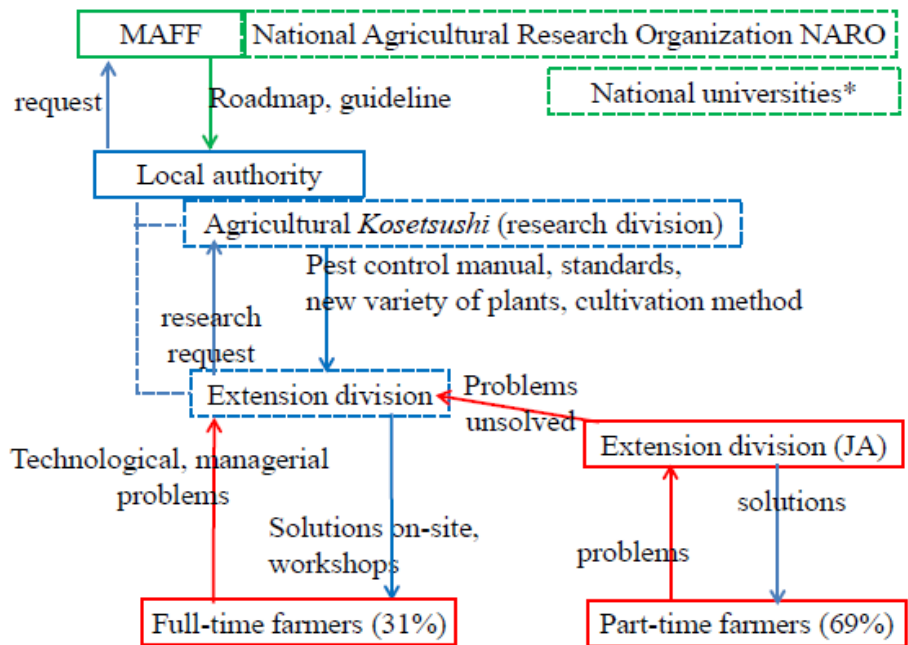
	Model 1		Model 2		Model 3		Model 4	
	FE	RE	FE	RE	FE	RE	FE	RE
Plant	Rice	Rice	Fruit	Fruit	Vegetable	Vegetable	Flower	Flower
N	564	564	564	564	564	564	564	564
Research effort allocated to agriculture other than forestry and fishery	0.143**	0.133**	0.133**	0.122**	0.119**	0.118**	0.116**	0.084**
	0.011	0.010	0.009	0.008	0.013	0.011	0.008	0.006
Location quotient of rice	-0.060	1.633*						
	1.222	0.832						
Location quotient of fruit			3.697*	1.412				
			1.620	1.335				
Location quotient of vegetable					-3.495**	-0.918		
					1.181	0.563		
Location quotient of flower							0.519	0.711
							0.700	0.404
_cons	-3.872*	-4.324*	-3.724*	-0.442	9.671**	6.939**	-5.437**	-2.603**
	1.830	1.745	1.826	1.938	1.975	1.670	1.093	0.881

### Notes

1. Standard errors are under coefficients.
2. Level of statistical significance: \*\* p<0.01; \* p<0.05.
3. Results of time dummies are not reported.

Except for fruit, there is no statistically significant relationship between agricultural cluster of a specific plant and research effort by agricultural *Kosetsushi* on the plant. This could be attributed to organizational characteristics of agricultural *Kosetsushi*. Unlike manufacturing *Kosetsushi*, there is a clear division of labor between research and diffusion at agricultural *Kosetsushi*.

Figure 2 Agricultural research and extension in Japan



Source: Author's own elaboration

MAFF = Ministry of Agriculture, Forestry and Fisheries. JA = Japan Agricultural Cooperatives. Dotted line means subsystems of national and local authorities. \* National universities in Japan were semi-privatized after the National University Incorporation Law of 2004.

Figure 2 shows how local needs for agricultural research are transmitted to agricultural *Kosetsushi*. MAFF defines two groups of farmers: full-time and part-time farmers. The former represents farmers whose income entirely comes from farming while the latter represents farmers who earn income from other occupations, such as manufacturing workers. The proportion of the former is 31.7% as of 2017, which implies that most of the individual agricultural producers are non-professional in Japan. In general, a small number of full-time farmers in a region let extension workers of local authorities know about their problems in production and management while part-time farmers in the region consult with extension staff of JA (Japan Agricultural Cooperatives) in that region, thereby exerting division of labor between public innovation intermediary (with a small number of local authority staff) and private innovation intermediaries (with many JA staff). Extension workers transfer research needs from local farmers to agricultural *Kosetsushi* in the form of research request. Such a feedback mechanism constitutes one of the key factors for agricultural *Kosetsushi* to select research topics in the next fiscal year. Other factors influential to research theme selection are requests from the local government and needs from major buyer, such as the flour industry and the chain restaurant industry. In light of information from different sources, agricultural *Kosetsushi* lays out the research plan and provides feedback to extension workers in the form of manual, seminars, and patents. The result suggests the possibility that knowledge creation at agricultural *Kosetsushi* reflects local industrial structures by tapping into various sources while

knowledge dissemination at extension stations fails to do so presumably because they are supposed to deal with all kinds of problems farmers face in everyday operation, which makes it necessary for extension centers to allocate resources evenly, creating mismatch between demand and supply.

Knowledge creation and dissemination by manufacturing *Kosetsushi* are closely associated with characteristics of regional innovation systems. This builds on the fact that researchers at manufacturing *Kosetsushi* frequently interact with local SMEs through technical consultation and company visit. Fukugawa (2016) shows that research activities of manufacturing *Kosetsushi* are responsive to local needs and the diffusion of research outcome also aligns with characteristics of regional innovation systems. Specifically, allocation of research effort fits better with that of local SMEs than the allocation of research effort by local universities. Furthermore, in prefectures where innovative activities of local SMEs are concentrated in biotechnology, manufacturing *Kosetsushi* tend to employ patent licensing for diffusion because biotechnology builds on analytical knowledge that could be better transferred via less interpersonal channels like licensing. On the other hand, in prefectures where innovative activities of local SMEs are concentrated in mechanical engineering, manufacturing *Kosetsushi* tend to employ technical consulting because mechanical engineering builds on synthetic knowledge that could be better diffused via more interpersonal channels. Overall, knowledge creation and dissemination by manufacturing *Kosetsushi* are closely associated with regional innovation systems.

In contrast, as shown in Figure 2, researchers at agricultural *Kosetsushi* do not directly engage in personal interactions with local farmers, which exhibits the biggest difference from manufacturing *Kosetsushi* in terms of organizational structure. With regard to the relationship between organizational features and technology transfer activities, previous studies on technology transfer organizations (e.g., university-based technology licensing offices) show that the technology transfer productivity, measured by the number of patents licensed to firms and royalty revenue, is affected not only by physical factors, such as location, but also by organizational factors, such as incentive mechanisms designed for staff of technology transfer organizations (Lach and Schankerman 2008; Fukugawa 2009; Amico-Roxas et al. 2011; Adekunle, 2013; Hsu et al. 2015). Similarly, the results suggest the possibility that a clear division of labor between research and diffusion makes research at agricultural *Kosetsushi* less responsive to local needs. It should be noted that there might have been different types of interactions between the diffusion and research arms according to plants they develop because Table 5 shows that potential impacts of organizational features are contingent on the type of a plant they research on. Future study should collect information on the linkage between the diffusion and research arms by plant, such as vegetable and fruit which exhibit opposite results.

Table 6 shows estimation results of Equation 2. Instead of including all the variables representing research field into the regression model, several variables are selected using factor analysis to reduce data. The result of factor analysis shows that two factors, of which eigenvalue exceed the value of one, can be extracted from the data and they are characterized as plant research and livestock research, respectively. Research fields highly correlated with the former are 1 plant breeding, 4 soil and fertilizer, 5 diseases and pests, and 12 machinery. In light of high correlation among variables indicated in Table 3, four independent variables are alternately introduced in the regression models. For illustrative reason, coefficients of different regression models are presented in the same column.

Coefficients of research on plant breeding, which appears to be the most important factor in agricultural product innovations, are positive but only rice and vegetable exhibit coefficients that are statistically significant. The elasticity of product innovation to research on plant breeding is 0.264 for rice and 0.239 for vegetable. This means that one percent increase in research input on plant breeding increases product innovations by 26.4% for rice and 23.9% for vegetable. Ito (1994) shows that the elasticity of output to technological knowledge stock in the agricultural sector is 0.09 in Japan (1960-1980), 0.29 in the US (1960-1980), 0.12 in India (1959-1980), 0.09 in Thailand (1967-1980), 0.08 in Taiwan (1955-1968), and 0.13 in the Philippines (1958-1968). In comparison to the estimated elasticity in other countries and Japan, the results obtained from the present study appear considerably high, except for the US. This stems from that independent variables are weighted by the proportion of researchers engaged in a specific plant to total number of researchers in agriculture, making estimated coefficients larger than those of original independent variables.

Table 6 Estimated random-effects Tobit regression models: Dependent variable= $\ln(\text{the number of new varieties registered})$ 

	Model 5	Model 6	Model 7	Model 8
Plant	Rice	Fruit	Vegetable	Flower
N	141	329	376	376
Log of research effort allocated to 1 plant breeding	0.264**	0.162	0.239**	0.077
	0.051	0.087	0.050	0.052
4 soil and fertilizer	0.485**	0.094	0.236**	0.067
	0.069	0.132	0.086	0.099
5 diseases and pests	0.257**	0.065	0.231**	0.022
	0.063	0.107	0.076	0.079
12 machinery	0.933**	0.255	0.249	0.192
	0.175	0.245	0.135	0.252

## Notes

1. Standard errors are under coefficients.
2. Level of statistical significance: \*\*  $p < 0.01$ ; \*  $p < 0.05$ .
3. Results of time dummies and constants are not reported.
4. Independent variables are introduced in the regression model alternately. Coefficients are shown in the same column for the illustrative purpose.
5. The number of observations vary across plants as different lagged structures are introduced to the regression models.

Table 6 shows that different types of research effort have different level of impacts on agricultural product innovations. Furthermore, there is a product-level variation in the way research effort exerts an effect on research outcome. In fact, the development of new varieties of rice and vegetable requires agricultural *Kosetsushi* to arrange a broad set of research inputs (i.e., researchers) while no research effort in a specific field exerts an effect on product innovations in fruit and flower. With regard to the relationship between human resource development and technology transfer productivity, previous studies on technology transfer organizations (e.g., business incubators) show that the diversity and quality of human resources do affect the success of technology transfer organizations (e.g., the number of new firms created) but its impact is contingent on technological fields and life cycle stages of startups to which they aim to give support (Fukugawa forthcoming). Similarly, the results suggest the possibility that the technology transfer productivity at agricultural *Kosetsushi* is contingent on product-level factors. The product-level factors would pertain not only to natural conditions, but also to economic conditions, such as appropriability. This implies that agricultural *Kosetsushi* play different roles in regional innovation systems according to these conditions which cannot be fully captured in the present study. Future study should incorporate detailed

information to analyze the process of decision making on resource allocation at agricultural *Kosetsushi*.

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