Chapter 2. ‘Out of field’ teaching in mathematics: Australian evidence from PISA 2015

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Abstract 'Out-of-field' refers to teachers teaching subjects for which they do not hold a subject-specific qualification. Theory and empirical evidence suggest it can adversely affect teachers' work and students' learning. Teacher shortages and aspects of school organisational practice have been explanations linked to out-of-field teaching. We draw on Australian PISA 2015 data to examine the extent to which these, together with teacher characteristics and other school context factors, influence the assignment of teachers to out-of-field mathematics teaching. While the results show that schools' experiences of teacher shortages were unrelated to out-of-field mathematics teaching assignment, greater school autonomy, which captures aspects of school organisational practice, reduced the likelihood of out-of-field assignment. The results show other school context variables implicated in the relationship between school autonomy and out-of-field teaching are school sector and students' parents' educational level. Particular teacher characteristics also associated with their risk of assignment to teach mathematics out-of-field. Implications for policy are advanced.

Keywords Mathematics, Multilevel logistic model, Out-of-field teaching, School autonomy, School sectors

1. Introduction

Calls to lift teacher quality in Australia generally follow whenever there is a decline in the country's international ranking in student performance in, for example, the Programme for International Student Assessment (PISA) which has shown a continuing decline in reading, science and particularly in mathematics (Thomson, 2021). The latest call was made by the Minister of Education and Youth who initiated yet another inquiry into initial teacher education partly in response to declining school standards (rankings) over the last two decades (Tudge, 2021). However, not all declines in school rankings may be related to teacher quality, especially in mathematics. An important contributing factor in the decline could be the assignment of teachers to teach subjects for which they are not qualified (Cobbold, 2017). In the literature, out-of-field teaching refers to when teachers teach subjects (content) for which they do not hold the subject-specific qualifications. For example, if a teacher is assigned to teach mathematics when he or she is instead qualified to teach chemistry and biology. In contrast, 'in-field' teachers have subject-specific qualifications and pedagogical content knowledge relevant for the subject.

The importance of teachers having subject qualifications is underscored by the fact that most learning in the secondary school context is content-specific and thus, depends on the corresponding knowledge domain. Student learning in the domain of mathematics involves a set of constructive processes in which individuals sequentially build, activate, elaborate and organise knowledge systematically. This requires teachers to create an environment in which students are able to engage in domain-specific learning activities and build on previous knowledge (Seidel & Shavelson, 2007). To do so effectively, teachers need to have content knowledge, among which Shulman (1986) distinguishes 1) subject matter content knowledge, 2) pedagogical content knowledge[1], and 3) curricular knowledge. By definition, out-of-field teachers of mathematics will lack the deeper knowledge of the subject that is necessary for teaching students at senior levels and inspiring them to continue studying the subject at the tertiary level. Teachers asked to teach out-of-field will lack content knowledge and be less effective in that situation, even if they are brilliant communicators and classroom managers. Empirical evidence has shown that students taught by in-field teachers achieve better in mathematics than those taught by teachers teaching out-of-field (Clotfelter et al., 2010; Dee & Cohodes, 2008; Goldhaber & Brewer, 2000).

Students taught by more knowledgeable teachers are more likely to achieve and be motivated to undertake higher level mathematics (Baumert et al., 2010; Hill et al., 2005), which in turn is important for ensuring a steady supply of not only mathematics graduates, but graduates of other physical and social science disciplines which have strong mathematical underpinning. These graduates have an important role in a modern economy and the demand for them continues to grow (Audit Office of New South Wales, 2019; Ingersoll & Perda, 2010; OECD, 2012; Office of the Chief Scientist, 2014; Productivity Commission, 2012; Queensland Audit Office, 2013; Smith, 2017; The Royal Society, 2007).

Out-field teaching also affects teachers. Teachers assigned to teach out-of-field in mathematics in the Teach for America programme were found to be at a higher risk of leaving the profession altogether than those assigned to teach in-field (Donaldson & Johnson 2010). Such teachers often feel a loss of professional identity and confidence (du Plessis, 2019; Hobbs, 2013; Sharplin, 2014).

Despite the adverse effects of out-of-field teaching on both students and teachers, as we discuss in the literature review the practice is widespread in many countries, including Australia (see Shah et al., 2020; Weldon, 2016). Ingersoll (2004) proposed two mechanisms to explain the prevalence of out-of-field teaching in the United States—teacher shortages and schools' organisational practices—but found support for only the second hypothesis. There is a knowledge gap in Australia about what drives the practice of out-of-field teaching in general and in mathematics, and which teachers are most affected by this practice. In particular, the two hypotheses proposed by Ingersoll (2004) remain untested in the Australian context. These are important to investigate because, as Ingersoll (1999) noted, many people including

[1] Pedagogical content knowledge goes beyond the knowledge content *per se* to include the dimension of subject knowledge content that is most germane for *teaching*.

in Australia (e.g., Prince & O'Connor, 2018), assume the problem of out-of-field teaching is poorly prepared teachers or not enough teachers, that can be remediated with higher training standards and expanded recruitment.

In this chapter, we draw on Australian PISA 2015 data, which for the first time included an optional teacher survey in addition to the principal and student surveys, to address this knowledge gap about the practice of out-of-field teaching in mathematics in Australia. In particular, we investigate the role of teacher shortages and aspects of school autonomy together with other school context characteristics (e.g., size, location, whether it is in the government, Catholic or independent sector) and teacher characteristics (e.g., age, gender, employment contract) to predict the probability of teachers' assignment to out-of-field teaching in mathematics.

2. Literature Review

Research on out-of-field teaching in the United States goes back many decades (Brodbelt, 1990; Council for Basic Education, 1986; Gardner, 1983; National Commission on Teacher Education and Professional Standards. Special Committee on the Assignment of Teachers, 1965; Robinson, 1985). It grew from a concern for equality in education, an enduring challenge for education policy not only in the United States but in many other countries as well (e.g., Coleman et al., 1966; Kozol, 1991; Teese et al., 2007). Evidence from the United States has shown that students from poor, minority and disadvantaged backgrounds are often taught by the least qualified teachers, which has contributed to poorer educational outcomes for those students (e.g., California Commission on the Teaching Profession, 1985; Darling-Hammond, 1987).

In 2001, the United States Congress passed the *No Child Left Behind Act*, with specific incentives for states to eliminate out-of-field teaching by requiring 'highly qualified'[2] teachers in all core academic subjects across all income groups. After nearly a decade and a half, it seems the situation—rather than becoming better—may in fact have worsened, at least in science and mathematics (Shah et al., 2019). The act was replaced by *Every Student Succeeds Act* in 2015, designed to increase local control by states and school districts and consequently improve student outcomes and teacher quality. The new act so far, according to Van Overschelde and Piatt (2020), seems to have produced perverse outcomes. Using administrative data for Texas, they showed out-of-field teaching increased considerably across all subjects after the act was passed compared to the situation before its introduction.

Most research on out-of-field-teaching in the United States has used data from the National Teacher and Principal Survey (formerly known as the *Schools and Staffing Survey* (SASS)) which has been conducted periodically since the mid-

[2] The Act defined this term to mean that teachers hold a bachelor's degree and state certification, and demonstrate content knowledge in the subjects they teach.

1980s. Estimates from these data show the proportion of mathematics classes taught by out-of-field teachers (without a major or minor in mathematics) ranged from 18% in 1988 to 35% in 2015; and, the proportion of students taught mathematics by out-of-field teachers ranged from 16% to 33% over the same period (Hill & Gruber, 2011; Hill et al., 2015; Morton et al., 2008; Seastrom et al., 2004; Shah et al., 2019).[3] The rate has tended to vary across teachers, schools and students. Less experienced teachers and those teaching low-track classes were more likely to be teaching out-of-field; and the practice has been found to be more prevalent in smaller schools and schools having high proportions of students from low socioeconomic backgrounds (Ingersoll, 1999).

Internationally, the 2008 *Teaching and Learning International Survey* (TALIS) revealed an average out-of-field teaching rate of 10% in mathematics and science in lower secondary schools across 21 countries—from 0.2% in Poland to 16% in Brazil (Zhou, 2012).[4] The rate was generally higher in schools that were small, in rural areas and having large numbers of part-time and temporary teachers. As the TALIS data exclude casual relief teachers, who tend to have higher rates of out-of-field teaching, the estimates derived from TALIS will generally be smaller than those derived from data which have a broader scope. This is one reason why the 5% combined rate for mathematics and science in Korea in TALIS is only half of the 10% in mathematics and one-fifth of the 25% in science that Kim (2011) reported, using a different country-specific Korean dataset. Kim similarly reported that out-of-field teaching in Korea was more common in small schools, outside big cities and in public schools. Using data from the 2013 survey of *Staff in Australian Schools* (SiAS), Weldon (2016) reported an out-of-field teaching rate of 20% in secondary school mathematics in Australia. The rate was higher among teachers of lower grades, younger and less experienced teachers, and teachers in rural and regional schools. While he found some variation in the rate across states, the differences across government, Catholic and independent sectors were small.

As mentioned, the two major sets of explanations put forth to explain the phenomenon (Ingersoll, 2004) have related first, to teacher shortages and recruitment difficulties in particular specialisms; second, to school organisational practice and administrative leadership, including the degree to which schools enjoy autonomy to make decisions concerning teacher appointments and deployment. However, both Ingersoll (2004) and Zhou (2014) found lack of evidence to support the teacher shortage hypothesis. It is possible that school principals faced with a need to cover a mathematics class, may assign an out-of-field teacher from the existing staffing pool to cover the class rather than hire an additional mathematics teacher from the

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[3] Out-of-field teaching has variously been measured in terms of the proportions of students, teachers or classes that are affected by the phenomenon. The choice of the measure depends on the data that are available, meaning that one has to be careful when comparing results from different studies (Ingersoll, 2019).

[4] Out-of-field teaching rate was measured as the percentage of mathematics and science teachers teaching out-of-field in the school.

external labour market, thereby saving on costs. In fact, when budgets are tight, this may be the only option available to the school. In such situations the principal may not report having experienced recruitment difficulties. Interestingly, Kim (2011) found high rates of out-of-field teaching in mathematics and science despite an apparent oversupply of teachers in Korea. Similarly, Ingersoll (2004) observed high rates of out-of-field teaching in English and social studies, subjects not generally known for having shortages. What this also means is that better training and recruitment of large numbers of new mathematics teachers, while worthwhile, may be unlikely to address the issue of quality mathematics teaching if teachers continue to still be assigned to teach out-of-field (Hoxby, 2004; Ingersoll, 2019).

Schools' organisation practices are an alternative explanation for out-of-field teaching. Decisions about these practices are made at different levels, including at the system and school level by principals. Regression analyses of data on secondary-level teachers from the *Schools and Staffing Survey* (SASS) in the United States found school leadership practices related to significantly lower rates of out-of-field teaching (Ingersoll, 2004). Unsurprisingly, Ingersoll found that schools that hired or assigned underqualified teachers (i.e., those who do not have a minor or a major in the subject they are assigned to teach) to cover vacancies had higher out-of-field teaching; and schools governed by district-level policies requiring new teachers to hold a minor or a major in the subject to be taught, tended to have less out-of-field teaching. Using the TALIS data, Zhou (2012, 2014) investigated the effect of school leadership (administrative tasks, enforcing rules and procedures, and principal accountability) and school autonomy (for teacher hiring and determining teacher salaries) on out-of-field teaching in mathematics and science.[5] He found administrative leadership did not have a significant independent effect on school-level out-of-field teaching. The aspect of school autonomy that mattered most was who had responsibility for teacher salary increases. Schools in which the principal had this responsibility tended to have lower rates of out-of-field teaching. In contrast, when teacher salary increases were decided by regional authorities, schools tended to have higher rates of out-of-field teaching. The Korean context provides further insights into the negative outcomes of central control and institutional rigidities pertaining to teaching hours, teacher contracts and the allocation of teachers to schools, all of which associated with higher rates of out-of-field teaching (Kim, 2011). Du Plessis, Gillies, and Carroll (2014) alluded to the role of school leadership in managing out-of-field teaching, noting that current practices are often about 'crisis management' rather than finding long-term strategic solutions.

Ingersoll (2004) found a strong relationship between class sizes and out-of-field teaching, with less out-of-field teaching in schools which had larger classes. Maximum class sizes are often mandated in industrial relations agreements and, therefore, increasing class sizes may not be an option for schools where such agreements

[5] The 2012 study included data for 21 out of 24 countries that participated in TALIS; the 2014 study included data for only 15 countries. Both studies modelled fixed effects for countries in analyses.

exist. School size may also limit the extent to which class sizes may be increased. This means some schools may opt to cancel classes or increase class sizes to avoid out-of-field teaching. Ingersoll found larger schools had less out-of-field teaching, but this relationship was weaker when the model included school organisation variables. Zhou (2012) also showed that smaller school size was significantly and independently associated with higher rates of out-of-field teaching. However, Zhou's subsequent study (2014) found school size to be unrelated. Whether the different result was due to differences between the samples or to other factors is unclear, and no explanation was suggested by Zhou (2014).

This literature review has highlighted the phenomenon of out-of-field teaching in mathematics in different countries and illustrated how its prevalence varies across different kinds of teachers, school contexts and datasets. While there has been little evidence to suggest teacher shortages as a significant factor in the assignment of teachers to out-of-field teaching, aspects of school organisational practices, particularly those related to school autonomy, seem to play a significant role.

3. Data

The Australian PISA 2015 consisted of surveys of students, teachers and principals.[6] A sample of 14,530 grade 10 students was drawn from 758 schools to complete the student survey. A total of 738 principals completed the school survey. The teacher sample included 16,234 teachers, of whom 11,715 responded to the teacher survey, a response rate of 72%. A unique common school identifier allowed the linking of school context data from the students' and principals' surveys to the teachers' data.

The teachers' survey did not contain a specific question about out-of-field teaching in mathematics, but it included the following question:

> Were any of the following [subjects] included in your teacher education or training programme or other professional qualification and do you teach them to Year 10 in the current school year?

Teachers' responses were collected in a matrix of two columns and eleven rows. The two columns were headed '*Included in my teacher education or training programme or other professional qualification*' and *'Teach it to Year 10 in the current*

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[6] The full technical details of the survey, including the sampling method, are in OECD (2017). Weights to account for the sampling design and non-response in the teacher survey are unavailable. However, student weights are available from the student survey. We use these to approximate teacher weights. We do this by assuming the same weight for each teacher in groups defined by state, sector and location of school. The sum of student weights in each group is divided equally among all teachers in the group.

school year'. The rows listed eleven subjects, including mathematics. Respondents selected all relevant boxes in this matrix. From teachers' responses to this compound question, 2,313 teachers were identified to be teaching mathematics to Year 10 in the current school year with 20% teaching it out-of-field. For teachers teaching mathematics to Year 10, a binary variable was constructed for the variable 'out-of-field' in mathematics. It was assigned a value 1 for teachers for whom mathematics was not included in their teacher education or training programme or other professional qualification; otherwise a value of 0 was assigned. Clearly, these data are limited to the extent that they do not reveal the number of classes these teachers were teaching, the number of students in classes, or whether they were teaching the subject at any other grade-level.

Personal characteristics of teachers assigned to teach mathematics

For our investigation of out-of-field teaching in mathematics, our effective sample consisted of data for 2,313 teachers. Teachers teaching mathematics out-of-field were, on average, younger than those teaching mathematics in-field (see Table 1). Relatively more of those teaching mathematics out-of-field were women and on temporary contracts, including fixed-term and casual contracts.

Table 1

In-field and out-of-field teachers teaching secondary school mathematics by personal characteristics, Australia

Characteristic		**n**			**%**		
		In-field	Out-of-field	Total	In-field	Out-of-field	Total
Gender	Female	876	249	1125	47.8	53.2	48.9
	Male	956	219	1175	52.2	46.8	51.1
	Sample size[1]	1832	468	2300	100	100	100
Qualification level	Lower than bachelor	89	22	111	4.9	4.7	4.8
	Bachelor	1416	353	1769	77.2	75.9	76.9
	Higher than bachelor	330	90	420	18.0	19.4	18.3
	Sample size	1835	465	2300	100	100	100
Hours of work	Full-time	1573	397	1970	86.0	85.9	86.0
	Part-time	257	65	322	14.0	14.1	14.0
	Sample size	1830	462	2292	100	100	100
Employment contract	Permanent	1592	377	1969	86.6	80.2	85.3
	Temporary	247	93	340	13.4	19.8	14.7
	Sample size	1839	470	2309	100.0	100.0	100.0

Professional development activities	≤3	768	185	953	41.8	39.7	41.3
	>3	1071	281	1352	58.2	60.3	58.7
	Sample size	1839	466	2305	100	100	100
Age (years)	Mean	43.8	40.4	43.1			
	Standard deviation	11.8	10.9	11.7			
	Sample size	1832	470	2302			

Source: PISA 2015

Note: 1 Sample size excluding missing values. The full sample has data on 2,313 teachers. Unweighted estimates.

School context of teachers assigned to teach mathematics

Australia's school education system consists of three sectors: government (public), Catholic systemic, and other independent systems, with complex government and private funding of each (Thomson, 2021). In 2020, the proportions of secondary students enrolled in each of the respective three sectors were 59%, 22% and 19%.[7] Assignment to out-of-field teaching was relatively less in independent than government schools. The schools where teachers were teaching mathematics out-of-field were, on average, smaller than the schools where they were teaching in-field (see Table 2). The proportion of teachers in each state and territory in the sample was not representative of the population because schools from smaller jurisdictions were oversampled to ensure reliable estimates for these jurisdictions. For example, New South Wales' share of teachers in the sample is 22%, which is less than its share (about one-third) of the total population. The weighted shares (not shown in the table), however, reflect the population shares more closely. Overall, relatively more teachers in New South Wales and Queensland schools were assigned to out-of-field teaching than in the other states and territories.

The binary variable 'shortage of teachers' represented principals' responses to the question of whether a school's capacity to provide instructions to students was hindered by a lack of teachers. It was coded as one if the response to the question was either 'to some extent' or 'a lot', and zero if the response was either 'not at all' or 'very little'. The question was about a general perception of teacher shortages, and not about a shortage in any specific subject. While this is less than ideal for capturing information on the shortage of mathematics teachers, it provides a reasonable proxy.

In the school survey, each principal was required to indicate who among the principal, teachers, the school board, local education authority and the national education authority had 'considerable' responsibility for each of twelve school

[7] https://www.acara.edu.au/reporting/national-report-on-schooling-in-australia/national-report-on-schooling-in-australia-data-portal/student-numbers

organisational practices. The principal could indicate multiple parties having responsibility for each of the practices. The twelve practices included decisions on hiring and firing teachers, setting staff salaries, allocating budget, setting the curriculum and operating student admission and discipline. The school autonomy variable was constructed by the OECD to measure the collective responsibility of the principal, teachers and the school board for these practices. Its value ranged from zero to one, with higher values indicating more autonomy. Schools that assigned teachers to out-of-field teaching were generally less autonomous than schools that assigned them to in-field teaching.

The last four variables in Table 2 were derived from the student survey. They capture aspects of the socioeconomic profile of the schools. For example, only 8% of out-of-field teachers compared to 14% of in-field teachers were in schools where more than 75% of parents of students possessed higher education qualifications.

Table 2

In-field and out-of-field teachers teaching secondary school mathematics by school context, Australia

School context		n			%		
		In-field	Out-of-field	Total	In-field	Out-of-field	Total
School size (X 100 students)	Mean	10.2	9.1	9.9			
	Standard deviation	4.4	4.2	4.4			
	Sample size[1]	1723	434	2157			
State	New South Wales	391	111	502	21.2	23.6	21.7
	Victoria	333	87	420	18.1	18.5	18.2
	Queensland	409	93	502	22.2	19.8	21.7
	South Australia	270	69	339	14.7	14.7	14.7
	Western Australia	206	40	246	11.2	8.5	10.6
	Tasmania	125	27	152	6.8	5.7	6.6
	Northern Territory	34	20	54	1.8	4.3	2.3
	Australian Capital Territory	75	23	98	4.1	4.9	4.2
	Sample size	1843	470	2313	100	100	100
Sector	Government	1078	303	1381	58.5	64.5	59.7
	Catholic	417	105	522	22.6	22.3	22.6
	Independent	348	62	410	18.9	13.2	17.7
	Sample size	1843	470	2313	100	100	100
Location[2]	Metropolitan	1310	316	1626	71.1	67.2	70.3
	Provincial	490	128	618	26.6	27.2	26.7
	Remote	43	26	69	2.3	5.5	3.0

	Sample size	1843	470	2313	100	100	100
School type	Co-educational	1504	393	1897	87.3	90.6	87.9
	Girls only	112	17	129	6.5	3.9	6.0
	Boys only	107	24	131	6.2	5.5	6.1
	Sample size	1723	434	2157	100.0	100.0	100.0
Shortage of teachers	No	1255	301	1556	77.1	74.5	76.6
	Yes	372	103	475	22.9	25.5	23.4
	Sample size	1627	404	2031	100	100	100
School autonomy	Mean	0.75	0.73	0.75			
	Standard deviation	0.21	0.21	0.21			
	Sample size	1699	428	2127			
% of indigenous students	≤25%	1779	443	2222	96.5	94.3	96.1
	>25%	64	27	91	3.5	5.7	3.9
	Sample size	1843	470	2313	100	100	100
% students not speaking English at home	≤25%	1592	417	2009	86.7	89.5	87.3
	>25%	244	49	293	13.3	10.5	12.7
	Sample size	1836	466	2302	100	100	100
% parents with higher education	≤75%	1586	429	2015	86.4	91.7	87.5
	>75%	250	39	289	13.6	8.3	12.5
	Sample size	1836	468	2304	100	100	100
% students taking vocational subjects	≤25%	1492	366	1858	81.2	77.9	80.5
	>25%	346	104	450	18.8	22.1	19.5
	Sample size	1838	470	2308	100	100	100

Source: PISA 2015

Notes: 1 Sample size excluding missing values. The full sample has data on 2,313 teachers. Unweighted estimates.

2 Metropolitan locations generally have populations of more than 100,000; provincial locations between 25,000 and 100,000; remote locations less than 25,000.

3. Method

The assignment of a teacher to teach out-of-field can be conceived as a joint decision of the teacher and the principal (school) with each party acting to maximise their own utility. Principals will assign teachers to out-of-field teaching if they think there are net benefits (utility) to the school from taking that action. In assessing the net benefits, the principal may consider the effect of the decision on factors such as the school's budget, the quality of instruction to students, parental expectations and teacher industrial relations. The principal may also take into consideration the state of the teacher labour market in the location of the school. The teacher's consideration may include factors such as the avoidance of retrenchment, career enhancement and the additional workload from out-of-field teaching.

The assignment of a teacher to out-of-field teaching can thus be put into a structural framework of supply and demand to be determined simultaneously. We can use the following to specify the principal's demand for, and the teacher's supply of, out-of-field teaching services:

$$y_{ip} = \boldsymbol{X}_i\boldsymbol{\beta}_p + \boldsymbol{Z}_i\boldsymbol{\gamma}_p + \epsilon_{ip} \quad (1)$$

$$y_{it} = \boldsymbol{X}_i\boldsymbol{\beta}_t + \boldsymbol{Z}_i\boldsymbol{\gamma}_t + \epsilon_{it} \quad (2)$$

where y_{ip} is the principal's utility from assigning teacher i to teach out-of-field; y_{it} is teacher i's utility from teaching out-of-field; $\boldsymbol{X}_i$ is a vector of individual teacher characteristics and $\boldsymbol{Z}_i$ is a vector of school context characteristics, the elements of which can vary in each equation; $\boldsymbol{\beta}_p$, $\boldsymbol{\beta}_t$, $\boldsymbol{\gamma}_p$ and $\boldsymbol{\gamma}_t$ are vectors of parameters to be estimated; and ϵ_{ip} and ϵ_{it} are the error terms in equations (1) and (2), respectively.

In practice, we do not observe y_{ip} and y_{it}. Instead, what we observe is a binary variable indicating whether a teacher is assigned to teach out-of-field or not. We can thus specify the decisions of the principal and the teacher as two binary variables:

$$I_{ip} = \begin{cases} 1 \; if \; y_{ip} > 0 \\ 0 \; if \; y_{ip} \leq 0 \end{cases} \quad (3)$$

$$I_{it} = \begin{cases} 1 \; if \; y_{it} > 0 \\ 0 \; if \; y_{it} \leq 0 \end{cases} \quad (4)$$

There are four possibilities with respect to the above specification:

$I_{ip} = 1 \; and \; I_{it} = 1$ (both the principal and the teacher derive a net benefit from out-of-field teaching)

$I_{ip} = 0 \; and \; I_{it} = 1$ (only the teacher derives a net benefit from out-of-field teaching)

$I_{ip} = 1 \; and \; I_{it} = 0$ (only the principal derives a net benefit from out-of-field teaching)

$I_{ip} = 0 \; and \; I_{it} = 0$ (neither the principal nor the teacher derives a net benefit from out-of-field teaching).

Only in situation a), in which the net benefits for both parties are positive, do we observe out-of-field teaching in the current data. In all other instances, there is no assignment to out-of-field teaching because the net benefit for at least one of the parties is not positive. For example, we do not observe teachers who may have assessed the net benefits to be non-positive and consequently resigned. This means we cannot distinguish between situations b), c) and d) in the current data and, hence, it is impossible to identify the demand from the supply.

Assuming situation a), which we observe in the current data, represents the equilibrium between the supply and the demand, we can estimate a reduced form logit model and calculate the probability of assignment to out-of-field teaching conditional on individual teacher characteristics and the school context. As the supply cannot be identified from the demand, we cannot determine, for example, whether a teacher's age is a significant factor in the decision of the teacher or the principal.

Our data have a two-level hierarchical structure, with teachers in the same school sharing similar school-level random effects, which makes it suitable for specifying the reduced form model as a multilevel logistic model. Multilevel models contain both fixed effects and random effects, which can be in the form of random intercepts and random coefficients. Assuming random intercepts only, for the sake of simplicity we can specify the model algebraically as:

	$y_{ik}^{*} = \boldsymbol{\alpha_{0ik}} + \boldsymbol{X}_{ik}\boldsymbol{\beta} + \boldsymbol{Z}_{ik}\boldsymbol{\gamma} + \ \epsilon_{ik}$	(5)
	$\alpha_{\boldsymbol{0ik}} = \boldsymbol{\alpha_0} + \vartheta_{0k} + \mu_{ojk}$	(6)

In this equation, y_{ik}^{*} is the underlying, unobserved latent utility of the joint decision of the principal and the teacher in the assignment of teacher *i*, in school *k*, to teach out-of-field; $\boldsymbol{X}_{ik}$ is a vector of individual teacher characteristics and $\boldsymbol{Z}_{ik}$ is a vector of school characteristics. $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ are vectors of parameters and ϵ_{ik} is the residual term whose distribution is standard logistic with mean 0 and variance $\pi^2/3$; and with $\vartheta_{0k} \sim N(0,\, \sigma_{\vartheta}^2)$ and $\mu_{oik} \sim N(0,\ \sigma_{\mu}^2)$. The first term, ϑ_{0k}, is the school effect and the second term, μ_{oik} , is the teacher effect.

In practice, y^* is unobserved, instead, we observe the binary variable:

	$I_{ik} = \begin{cases} 1 \; if \; y_{ik}^{*} > 0 \\ 0 \; otherwise \end{cases}$	(7)

where one indicates assignment of teacher *i* to out-of-field teaching and zero indicates assignment to in-field teaching.

The probability of assignment to out-of-field teaching is:

	$\mathrm{Prob}(I_{ik} = 1) = \Phi\ (\boldsymbol{\alpha_{0ik}}+\boldsymbol{X}_{ik}\boldsymbol{\beta} + \boldsymbol{Z}_{ik}\boldsymbol{\gamma})$	(8)

where Φ is the logistic cumulative distribution function. Using maximum likelihood, we can estimate the parameters in this equation.

4. Results

The results below come from estimating the multilevel logit model with random intercepts as in equation (8). Several versions of the model are estimated, each nested in the one following. The models are estimated using the sample of teachers teaching mathematics, with missing data deleted listwise, which reduced the effective sample size from 2,313 to 1,965.[8] We first discuss the proposed relation of school autonomy to out-of-field teaching followed by an assessment of other fixed effects.

[8] Approximate weights as explained in footnote 5 are used in the calculations.

Effect of school autonomy

Model 1 is the unconditional mean model without any explanatory variables (see Table 3). It shows the intraclass correlation (ICC) of 5.3%, which is the proportion of the total variation in out-of-field teaching due to differences between schools. Although this is relatively small, a multilevel model is still appropriate because it will provide statistically efficient estimates of the effects and the model is theoretically justifiable.

The results from Model 2, which includes school autonomy as the only explanatory variable, show very little change in the ICC from Model 1. However, the likelihood ratio test comparing Models 1 and 2 is highly significant, which means that Model 2 is a significant improvement in fitting the data. The results also show that school autonomy is a statistically significant factor in the assignment of teachers to out-of-field teaching in mathematics, which probability is significantly lower in schools reporting higher levels of autonomy. In a variation of Model 2, we replaced school autonomy by shortage of teachers as the only explanatory variable to assess the teacher shortage hypothesis. The results (not shown in the table) supported findings of previous studies that reported teacher shortages was not a significant factor in the assignment of teachers to out-of-field teaching (e.g., Ingersoll, 2004; Zhou, 2014).

Model 3 extends Model 2, by adding all individual teacher characteristics (gender, age, qualification, employment contract, hours of work, professional development activities) as explanatory variables. Age and age-squared are included to capture potential non-linear effects of age. The results show that school autonomy continued to exert an independent significant effect of similar magnitude on out-of-field teaching as in Model 2. The likelihood ratio test showed improved model fit when teacher characteristics were included versus the previous model. The effects of the teacher characteristics are discussed in the next section.

In Model 4, school context variables (school size, state, school sector, location, school type, % Indigenous students, % students not speaking English at home, % students' parents with higher education qualifications, % students taking vocational subjects) were added as explanatory variables at level 2. The effect of school autonomy was considerably reduced and became statistically non-significant, suggesting that the relationship between school autonomy and the assignment of teachers to out-of-field teaching is confounded by school context factors. Two potential confounders were the school sector, and education level of students' parents. Bivariate analyses (not reported in detail) show the school sector to be a strong predictor of both school autonomy, and assignment of teachers to teach out-of-field, confirming its confounder role. Parallel analyses with respect to education level of students' parents similarly confirmed its confounder role.

Table 3
Effects of school autonomy on assignment of teachers to out-of-field teaching in secondary school mathematics, Australia

Explanatory variable	Model 1	Model 2	Model 3	Model 4
	Log odds (SE)	Log odds (SE)	Log odds (SE)	Log odds (SE)
School autonomy	Excluded	-0.99 (0.41) **	-0.93 (0.40) **	-0.10 (0.44)
Level 1 variables	Excluded	Excluded	Included	Included
Level 2 variables	Excluded	Excluded	Excluded	Included
Constant	-1.478 (0.08) ***	-0.70 (0.32) **	-1.79 (0.98) **	-1.63 (1.00)
Random effects parameter				
School (variance) σ_{ϑ}^{2}	0.18 (0.16)	0.16 (0.15)	0.13 (0.15)	0.01 (0.12)
Intraclass correlation (ICC)	0.05 (0.04)	0.05 (0.04)	0.04 (0.04)	0.00 (0.04)
Information criterion				
Akaike (AIC)	1932	1928	1899	1897
Bayesian (BIC)	1943	1945	1960	2065

Source: Authors' calculations based on data from PISA 2015.
Notes: * Significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent. Standard errors in parentheses.

The school autonomy composite measure captured overall organisational practices for which the school (principal, teachers and school board) had considerable responsibility. The composite measure included 36 constructs. To assess the effect of each, we re-estimated Model 5 36 times, substituting the school autonomy variable by each construct coded as a binary variable. For example, a value of one for the first construct indicated that the principal had considerable responsibility for hiring teachers and zero indicated otherwise. The results showed only 5 out of 36 constructs had significant independent effects on out-of-field teaching, after controlling for teacher characteristics and the school context (see Table 4 for abridged results).[9] In the table, Models 5 to 8 relate to school practices for which either the principal or teachers had considerable responsibility. Each of these practices was associated with a reduction in a teacher's probability of being assigned to out-of-field teaching. In contrast, the practice for which the school board had considerable responsibility increased the probability of out-of-field teaching (see Model 9). These results raise interesting issues about the agency of the principal, teachers and the school board in relation to the assignment of teachers to out-of-field teaching.

[9] Analyses showed that none of the practices for which the local or the national education authority had considerable responsibility had a significant independent effect on out-of-field teaching.

Table 4

Effects of constructs of school autonomy on assignment of teachers to out-of-field teaching in secondary school mathematics, Australia

Explanatory variable	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**
	Log odds (SE)	Log odds (SE)	Log odds (SE)	Log odds (SE)	Log odds (SE)
Formulating school budget (principal)	-0.28 (0.15) *	Excluded	Excluded	Excluded	Excluded
Selecting teachers for hire (teachers)	Excluded	-0.55 (0.18) ***	Excluded	Excluded	Excluded
Deciding budget allocations within school (teachers)	Excluded	Excluded	-0.52 (0.18) ***	Excluded	Excluded
Approving students for admission to school (teachers)	Excluded	Excluded	Excluded	-0.51 (0.24) **	Excluded
Firing teachers (school board)	Excluded	Excluded	Excluded	Excluded	0.84 (0.34) **
Level 1 variables	Included	Included	Included	Included	Included
Level 2 variables	Included	Included	Included	Included	Included
Constant	-1.48 (0.97)	-1.66 (0.97) **	-1.56 (0.97)	-1.65 (0.97) *	-1.83 (0.95) *
Random effects parameter					
School (variance) σ_{ϑ}^{2}	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Intraclass correlation (ICC)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Information criterion					
Akaike (AIC)	1892	1886	1885	1889	1890
Bayesian (BIC)	2054	2048	2046	2051	2052

Source: Authors' calculations based on data from PISA 2015.

Notes: * Significant at 10 per cent; ** significant at 5 per cent; *** significant at 1 per cent. Standard errors in parenthesis.

Mean marginal effects

The effects of explanatory variables in logit models are often expressed in terms of log odds. Marginal effects, on the other hand, summarise the effects of explanatory variables in terms of the model's predictions (Mize, 2019). They allow us to express the results in the probability metric, often the original measure of the dependent variable, and are particularly useful for interpreting the effects of categorical variables. The marginal effect is the difference in the prediction of an event at two levels of an explanatory variable, controlling for all other variables in some way. The non-linearity of the logit model means that the marginal effect is not constant over a range of values of other variables in the model. Several methods are thus used to report the marginal effect. A common practice is to calculate and report the mean marginal effect because of its better statistical properties compared to the alternatives (Cameron & Trivedi, 2005). Mean marginal effects are estimated by calculating marginal effects for every observation in the sample and then averaging those effects. For continuous explanatory variables, the adjusted predictions at representative values of the variables are instead calculated.

The mean marginal effects in Table 5 relate to Model 4. The constant term, 0.194, represents the overall probability of assignment to out-of-field teaching in mathematics. Statistically, men and women were equally likely to be assigned to out-of-field teaching. Similarly, teachers' qualification levels had little effect on the assignment. On the other hand, teachers on temporary contracts were 6.3 percentage points more likely to be assigned to out-of-field teaching than those on permanent contracts. This is a substantial difference as the overall probability of assignment was only 19.4%. The result may reflect the lack of bargaining power of temporary teachers in the teacher labour market.

Age had a significant effect on whether a teacher was assigned to out-of-field teaching. Although correlated with length of teaching experience, it should be noted that age is not identical, given different career entry points and career interruptions. Its effect is illustrated in Figure 1, which shows the adjusted predicted probability of assignment to out-of-field teaching at different ages. While the probability generally declined with age, the change was not linear. The youngest group of teachers (20-24 years), which included a large majority of first-year teachers, was somewhat less likely to be assigned to out-of-field teaching than those in the adjacent 25-29 years group. This suggests that schools are perhaps more sensitive to the needs of first-year teachers than is commonly believed. If this is true, and further research can validate, then it is an acknowledgement by schools of the significant challenges of pedagogy and classroom management faced by new teachers without the additional burden of out-of-field teaching, which has the potential to reduce their chances of a successful transition and retention in the teaching profession. Teachers aged 60 years or older were significantly less likely to be assigned to out-of-field teaching. This perhaps reflects the preferences of older, senior teachers, who often carry more weight in schools' decisions. On the other hand, it may also reflect schools' preferences to assign their most senior and experienced teachers to senior classes where subject specialist teachers are believed to be more important.

Teachers in the states of Western Australia and Tasmania were more than 4 percentage points less likely to be assigned to out-of-field teaching than teachers in the base state of New South Wales. The differences, while not large, were statistically significant and could be reflecting institutional factors not evident from the current data. Similarly, teachers in provincial school locations were 4.2 percentage points less likely to be assigned to out-of-field teaching than teachers in metropolitan schools, despite generally 'thinner' teacher labour markets in provincial locations. In contrast, Ingersoll (2004) found out-of-field teaching rates in United States provincial and city locations were not significantly different, a result which could have been affected by the inclusion of district size, a variable which is likely to be strongly correlated with school location, as an independent variable in his model.

While teachers in Catholic schools were just as likely to be assigned to out-of-field teaching as teachers in government schools, those in independent schools were 4.3 percentage points less likely to be. Interestingly, unlike teachers in all-boys schools, those in all-girls schools were 7.7 percentage points less likely to be assigned than those in coeducational schools. In schools where more than 25% of students spoke a language other than English at home, teachers were 4.7 percentage points less likely to be assigned to out-of-field teaching; in schools where more than 25% of students studied vocational subjects they were 4.4 percentage points more likely to be assigned, compared to the corresponding base categories. The average probability of assignment to out-of-field teaching declined by the size of school, from 25% in the smallest schools to approximately 8% in the largest (Figure 2). The difference was highly significant, and the results are consistent with the findings of Zhou (2012) but not those of Ingersoll (2004) and Zhou (2014). Whether the results are different because different model specifications and data were used in each study is difficult to ascertain.

Table 5

Mean marginal effects: the probability of assignment of teachers to out-of-field teaching in secondary school mathematics, Australia

Characteristic	Level	Estimate	SE	*p*-value
Gender (base = Female)	Male	-0.015	0.019	0.422
Age (Years)		-0.003	0.001	0.000
Qualification level (base = Bachelor)	Lower than bachelor	0.020	0.047	0.676
	Higher than bachelor	0.020	0.024	0.386
Employment contract (base = Permanent)	Temporary	0.063	0.030	0.034
Hours of work (base = Full-time)	Part-time	0.022	0.030	0.453
Professional development activities (base = ≤3)	>3	-0.002	0.019	0.903
School size (X 100 students)		-0.007	0.002	0.001
State (base = New South Wales)	Victoria	-0.003	0.031	0.929
	Queensland	-0.024	0.030	0.430
	South Australia	-0.004	0.032	0.901
	Western Australia	-0.048	0.032	0.141
	Tasmania	-0.040	0.035	0.253
	Northern Territory	0.001	0.091	0.988
	Australian Capital Territory	-0.005	0.049	0.924
Sector (base = Government)	Catholic	0.005	0.026	0.838
	Independent	-0.043	0.030	0.151
Location (base = Metropolitan)	Provincial	-0.042	0.023	0.060
	Remote	0.099	0.107	0.357
School type (base = Coeducational)	Girls only	-0.077	0.037	0.039
	Boys only	0.018	0.050	0.724
Shortage of teachers (base = No)	Yes	0.002	0.025	0.940
School autonomy		-0.016	0.023	0.476
% Indigenous students (base = <25%)	>25%	-0.017	0.055	0.756
% students not speaking English at home (base = <25%)	>25%	-0.047	0.025	0.058
% parents with higher education (base = ≤75%)	>75%	-0.048	0.030	0.109
% students taking vocational subjects (base = ≤25%)	>25%	0.044	0.026	0.088
Constant		0.194	0.009	0.000

Source: Authors’ calculations based on data from PISA 2015.

Figure 1
Adjusted prediction of assignment to out-of-field teaching in secondary school mathematics with 95% confidence interval by age of teacher, Australia

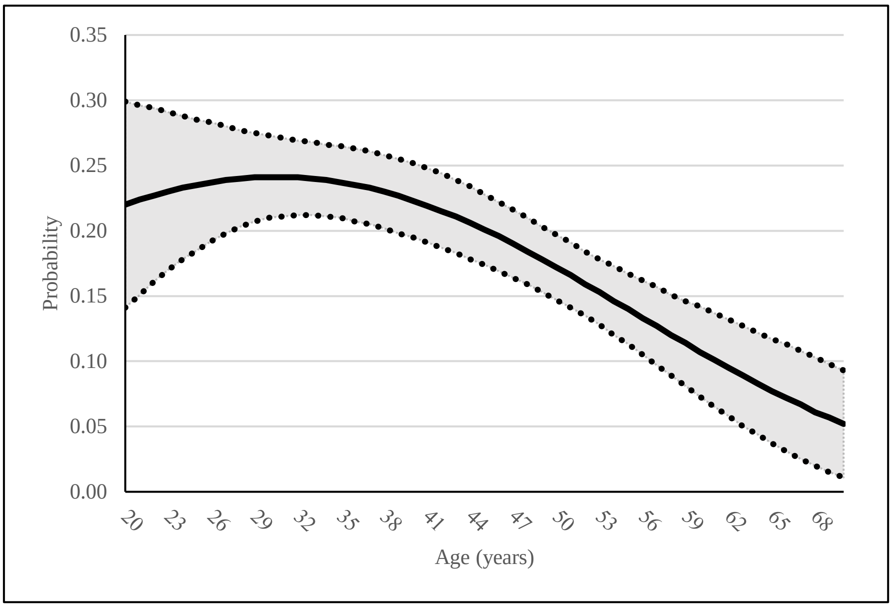
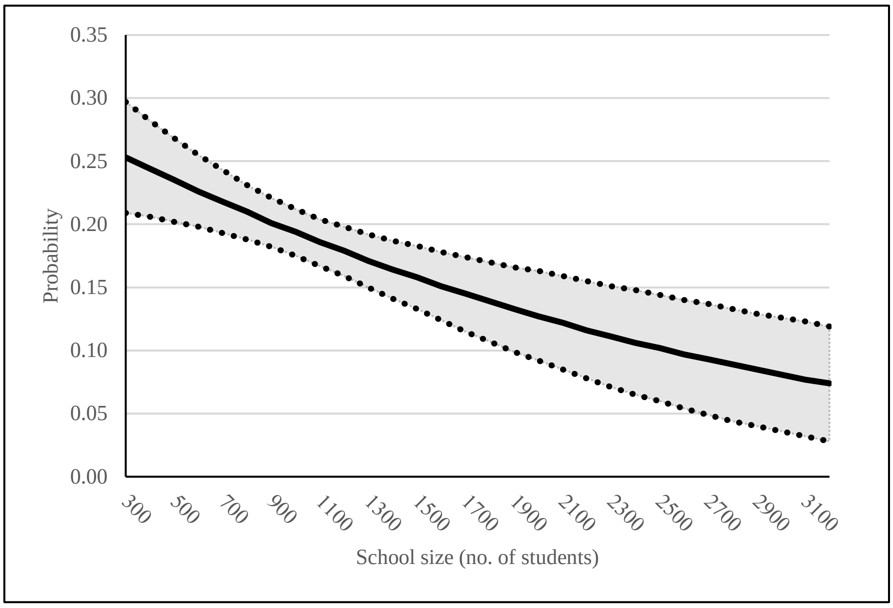


Figure 2
Adjusted prediction of assignment to out-of-field teaching in secondary school mathematics with 95% confidence interval by size of school, Australia



5. Discussion

We designed this study to explore the assignment of a teacher to out-of-field teaching in mathematics, conceived as a joint decision between the teacher (supply) and the school (demand). As identification of the supply from the demand was not possible, we used a reduced form multilevel logistic model to determine which teacher characteristics and school context factors associated with the assignment of a teacher to out-of-field teaching in mathematics. Two school context factors that were of particular interest were the school's reported teacher shortage, and level of autonomy.

Consistent with what others have reported in the literature (e.g., Ingersoll 2004, Zhou 2014), we did not find supporting evidence to suggest that the assignment of a teacher to out-of-field teaching in mathematics was related to the school's general subject-wide perception of teacher recruitment difficulties. Thus, as noted by Ingersoll (1999), in the Australian context too, increasing the total supply of qualified mathematics teachers may not reduce out-of-field teaching in the subject, nor address the structural and systemic problems of uneven distribution of in-field mathematics teachers across different types of schools.

Aspects of school autonomy, especially those related to budget allocation, significantly reduced a teacher's probability of assignment to out-of-field teaching in mathematics. These effects were confounded by other school context factors—mainly, whether the school was in the government, Catholic or independent sector, and the educational level of the students' parents in the school. These confounders strongly correlate with the differential funding allocations that schools receive, which we believe makes a difference to whether a school assigns a teacher to teach out-of-field in mathematics. When private and public funding sources are combined, non-government schools (especially independent schools) are much better funded than government schools (Thomson, 2021). We conjecture that the better funding and its certainty enables these schools to develop long-term plans for recruiting, and holding onto, suitably qualified staff. It also allows them to operate with more staff than the bare minimum, using this spare capacity to meet short-term needs. Unlike government schools with very tight budgets, independent schools thus need to rely less on the short-term teacher labour market, which is inherently riskier in terms of finding qualified teachers when needed. Our analyses show temporary teachers were at a much higher risk of being assigned to out-of-field teaching than teachers on permanent contracts. Highly educated parents have more agency to influence schools with regard to the quality of the teachers hired by the schools their children attend. It should be noted that these parents, because of their higher incomes and socioeconomic status, often choose well-resourced, independent schools for their children (Thomson, 2021).

School size and location are structural factors which were found to be significant determinants of the assignment of teachers to out-of-field teaching. Schools that were small and in remote locations were more likely to have teachers teaching mathematics out-of-field. These factors were also identified by Kim (2011) in the context of Korea, and are challenging to address from a policy perspective. Smaller schools have smaller budgets and can only employ a limited number of teachers. When this is combined with mandated restrictions on class size, the compulsory curriculum that each school is required to deliver, and student subject choices, the task of assigning teachers to classes in small schools so that all classes are taught by in-field teachers becomes difficult, if not impossible. In remote locations, with low population densities and smaller schools, an additional problem is that of thin teacher labour markets. Addressing these issues requires system-wide incentives for recruiting and retaining qualified teachers in these locations. Recruiting teachers who hold multiple subject qualifications can reduce the scale of the problem, not only in small and remote schools but all schools. Many teachers prepare for two subject methods as part of their initial teacher education course, the first related to their major undergraduate study and the second to their minor. However, mathematics teachers typically qualify to teach only mathematics (as a 'double major'). One criticism of the idea for mathematics teachers to qualify in an additional subject, is that it risks producing teachers who have breadth of knowledge but may lack depth. Online learning for students provides an alternative solution for some of these structural problems. However, the jury is still out about its effectiveness for all students. Lessons from the current COVID-19 pandemic may provide greater understanding about what works and for whom in this regard.

Teachers in schools containing a high proportion of students who speak a language other than English at home had lower probability of teaching out-of-field in mathematics than teachers in other schools. While on first reflection this result seems counterintuitive, many recent migrant families from East, South-east and South Asia are highly 'aspirational' and tend to enrol their children in high-performing, well-resourced, non-government schools (see Ho, 2020). These, as discussed above, tend to assign relatively fewer teachers to out-of-field teaching.[10]

Upskilling and professional development to bring teachers' content knowledge and qualifications to an acceptable level are possible policy options that have been suggested for reducing the prevalence of out-of-field-teaching and consequent adverse effects on student outcomes (Goos et al., 2020; Kim, 2011; Prince & O'Connor, 2018). Faulkner et al. (2019) provided examples of such programmes in Ireland, England and Australia, which in the first two countries led to in-field qualifications. A programme was introduced in the Australian state of Victoria in 2021 that leads to in-field qualifications in mathematics for teachers who are currently teaching mathematics out-of-field to grades 7-10.[11] For retraining programmes to be successful they must be well-designed and participating teachers carefully selected (du Plessis, 2019; Faulkner et al. 2019; Hobbs, 2013; Hobbs & Quinn, 2020; Schueler et al., 2015). Goos et al. (2020) outlined several design principles underpinning the development and delivery of these programmes and stressed the importance of properly coordinating face-to-face and computer-mediated instruction in a blended programme to support active learning, peer interaction, access to a wide range of resources, and opportunities to apply new knowledge in the workplace to enhance pedagogical richness. Professional development which does not necessarily lead to in-field qualifications, and mentoring for in-field and out-of-field teachers of mathematics, can surely only improve outcomes for students. The STEM Professionals in Schools programme organised in conjunction with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which is the premier, public science research organisation in Australia, is one that offers mentoring by professional scientists to teachers.

[10] Some families enrol their children in government schools, but these tend to be highly selective and well-resourced.

[11] https://www.education.vic.gov.au/school/teachers/classrooms/Pages/pd-secondary-maths-science-initiative.aspx

6. Conclusion

Out-of-field teaching of mathematics is a serious and pervasive issue in Australia, affecting both teachers and students. The analyses reported in this chapter show that the problem is manifested unevenly in terms of which teachers are assigned to teach mathematics out-of-field, and in which contexts. While structural factors such as size of school and location play a major role, our analyses highlighted other important contextual factors having indirect association with schools' funding. We deduce that schools having better, long-term funding, have an advantage in recruiting qualified mathematics teachers on permanent contracts, reducing out-of-field mathematics teaching in those schools. In contrast, schools on tighter and less predictable budgets having short-term funding are at a disadvantage. As these schools tend to rely on the temporary teacher labour market to fill short-term vacancies, they run a higher risk of not being able to find a teacher with the right subject qualification at the right time. The resulting disparity in the distribution of qualified mathematics teachers across schools exacerbates the existing divide in the quality of education across socioeconomic groups. While eliminating out-of-field teaching in mathematics across all schools may be a daunting aim, the uneven distribution of in-field mathematics teachers and resulting inequitable effects on students should be a policy concern in its own right. This should be prioritised in the deployment of teachers to schools and funding decisions. Schools can also monitor each student's exposure to out-of-field teaching to ensure no student is cumulatively inequitably exposed. These data would be useful to inform the system level, especially in government run schools, on where to best allocate resources to reduce the incidence and effects of out-of-field teaching in mathematics.

School principals' decisions on whether to assign teachers to teach subjects for which they are not qualified vary not only with the level of funding available to them but also on whether there is medium to long-term certainty in this funding. Current funding decisions tend to favour non-government schools, providing them with more and predictable funding per student, which enables them to plan stable and secure staffing. Out-of-field teaching of mathematics is unlikely to improve until school systems acknowledge that principals and school communities can find themselves between a "rock and a hard place" when assigning teachers to classes because of their circumstances. Identifying which teachers, in which contexts, are most likely to be assigned to out-of-field teaching in mathematics is the first step to inform policymakers and school leadership who have the agency to address the issue.

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