Broadband Internet and the self-employment rate: a cross-country study on the gig economy*

Piotr Denderski† Florian Sniekers‡

January 25, 2020

Abstract

Has the access to broadband Internet changed the composition of employment between payroll and self-employment? We propose a new theory of self-employment based on frictions in the goods and labour market and use variation in broadband access across a panel of OECD countries to test the theory's empirical predictions. To account for the possible endogeneity of broadband Internet, we instrument broadband adoption by a logistic diffusion model in which the availability of pre-existing technologies predicts broadband penetration. We find that faster Internet prompts more self-employment and lower unemployment. In our theory, this combination implies that the overall improvements in market efficiency stemming from advances in ICT are stronger in the goods than in the labour market.

JEL classification: J23, O33
Keywords: Self-employment, Internet, Gig economy

* We want to thank Eric Bartelsman, Ken Burdett, Pieter Gautier, Espen Moen, Markus Poschke, Thijs van Rens, Ludo Visschers, Makoto Watanabe and Emircan Yurdagul for valuable comments and suggestions on earlier versions of this draft. We have also benefited from the discussion with participants of seminars in Leicester, Munich and Tilburg, the Search and Matching Workshops in Aix-en-Provence, Mainz and Sjandberg, the Warsaw International Economic Meeting, the Annual Congress of the European Economic Association in Geneva and the Royal Economic Society Meeting in Bristol.

† University of Leicester School of Business, University Road, LE1 7RH Leicester, United Kingdom and Institute of Economics, Polish Academy of Sciences, Nowy Świat 72, 00-330, Warsaw, Poland; email: `piotr.denderski@le.ac.uk`, tel: + 44 (0) 116 252 3703

‡ Department of Economics, Tilburg University; Warandelaan 2, 5037 AB Tilburg, the Netherlands, email: `f.j.t.sniekers@uvt.nl`, tel: +31 13 466 2572.

1 Introduction

In the popular press, there is the widespread perception that improvements in communication technologies have contributed to the rise of non-standard employment relationships, in particular own-account work and self-employment.[1] This changing nature of work is generally believed to have important effects on both firms' business models and workers' socioeconomic security.

Increased access to broadband Internet has been accompanied by the development of new apps that allow people to supply their labour freely as handymen or cab drivers, supposedly resulting in a "gig economy" based on self-employment and freelancing relationships (Abraham, Haltiwanger, Sandusky, and Spletzer, 2018). Despite its intuitive appeal, however, the origin story of the gig economy has not been formally tested. Moreover, as we will document later, most OECD countries did not experience recent increases in self-employment rates. In this paper we therefore study the effect of broadband Internet penetration on self-employment rates.

We present a stylised theoretical framework that captures the changing incentives to become self-employed as the result of improvements in communication technologies. These improvements are assumed to reduce market frictions, allowing self-employed workers to find consumer demand more easily. We embed this mechanism in a model in which workers choose to become self-employed or search for a job. In the model, risk-averse workers trade the risk of not being able to sell their production in self-employment due to frictions in the goods market against unemployment risk and rent extraction by large firms in payroll employment. Payroll employees, however, receive insurance against the goods market risk: they obtain labour income even if their production cannot be sold in the goods market. Our model therefore relies on two natural ingredients: the risks involved in two frictional markets, and the size of firms that is large relative to self-employed sellers that allows firms to provide insurance. In this environment, the composition of employment arises endogenously as a mixed-strategy Nash equilibrium in the career-type-choice game.

We use the model to derive clean predictions regarding the impact of improvements in communication technologies on the self-employment rate. Although an increase in self-employment may seem inescapable from the assumption that advances in ICT reduce goods market frictions, this conclusion does not follow immediately, for two reasons. First, we also allow large firms to benefit from the same reduction in goods market risk as self-employed workers. Second, in line with the literature (Krueger, 2000, Martellini and Menzio, 2018), we allow advances in ICT to reduce labour market frictions as well. Such reductions in labour market frictions could make searching for a payroll job more attractive. We show that decreases in goods market frictions unambiguously increase the self-employment rate and decrease unemployment, while decreases in labour market frictions decrease the self-employment rate but leave the fraction of unsuccessful job applicants unchanged. A reduction in the goods market frictions increases returns to self-employment, constituting a *pull* factor. Inversely, if the matching efficiency in the labor market were to decrease, it would result in *push* towards self-employment.

We use variation in broadband access across a panel of OECD countries to estimate the effect

[1] See e.g. The Economist of December 30, 2014 ("Workers on tap" and "There's an app for that") or Roose (2014).

of broadband Internet on self-employment and unemployment rates. To account for the possible endogeneity of broadband Internet, we instrument broadband adoption by a logistic diffusion model in which the availability of pre-existing technologies predicts broadband penetration, just as in Czernich et al. (2011). Our results confirm the origin story of the gig economy: faster Internet prompts more self-employment. We also find that faster Internet decreases unemployment. This combination lends support to our interpretation that improvements in communication technologies have increased the incentives to become self-employed. In particular, it leads us to conclude that the overall improvements in market efficiency stemming from advances in ICT are stronger in the goods than in the labour market.

We make three contributions to the literature. Firstly, we contribute to the literature on the effects of modern technologies on economic change. Preceding the rise of the gig economy, Blau (1987) and Fairlie (2006) showed the importance of technological change, and personal computers in particular, to explain U.S. trends in self-employment. We follow Akerman et al. (2015), Czernich et al. (2011), Hjort and Poulsen (2019), Kolko (2012), and Audretsch et al. (2015) in focusing on the impact of broadband, but investigate its effect on the composition of employment. Although economic development has generally been associated with decreases in self-employment rates, we find that the arrival of broadband Internet has halted three quarters of the average downward trend in self-employment rates. Indeed, our counterfactual analysis finds that self-employment would have been much lower in the absence of broadband Internet.

Our second contribution concerns the explanation of cross-country differences in self-employment rates. Many papers (see e.g. Acs et al. (1994), Blanchflower (2000), Parker and Robson (2004), Robson and Wren (1999), Staber and Bgenhold (1993), Torrini (2005), and Kumar (2012)) focus on institutional variation to explain the large differences across countries. With our focus on the role of modern technologies, we add a new dimension to this literature, and we show that our findings are robust to the inclusion of important institutional variables. As our theory also has empirical predictions for unemployment rates, our focus is not constrained to self-employment. Closely related to our theoretical framework are therefore papers that address the joint determination of payroll employment, unemployment and self-employment rates across countries. Poschke (2018) and Feng et al. (2018) explain variations in employment status across a wide range countries, while Rud and Trapeznikova (2018) focus on Sub-Sahara Africa. All stress the importance of labour market frictions, as we do, but do not consider goods market frictions. Only Feng et al. (2018) considers developments over time, but focuses on increases in productivity rather than decreases in frictions.[2]

Finally, we propose a novel theory behind selection into self-employment. In fact, our model is orthogonal to the bulk of earlier work summarized succinctly in Parker (2004). This literature focusses on individual heterogeneity as the main determinant of becoming self-employed. For instance, Lucas (1978), Jovanovic (1982) and Poschke (2013) assume that being self-employed requires a separate skill, while De Meza and Southey (1996) find that self-employed entrepreneurs are simply more optimistic than employees. Our theory relies on risk aversion, similar to Kihlstrom and Laffont (1979). However, unlike their case, our theory does not rely on any

[2] Other papers model and estimate the flows across payroll, self- and unemployment in a single country, and assess counterfactual policies (see e.g. Bradley (2016)) and Narita (2019), or business cycle fluctuations (e.g. Visschers et al. (2014)).

ex-ante differences among individuals. Similar to Rissman (2003), self-employment is an alternative to searching for a job and large firms offer insurance against goods market risk. However, she assumes returns to self-employment are drawn from an exogenous distribution riskier than the wage distribution. We offer a model that endogenously generates those risk differentials.[3] Moreover, our model explains why improvements in matching efficiency in the labor market do not necessarily result in trends in unemployment, which is considered a challenge for standard labour market models that do not allow for self-employment (Martellini and Menzio, 2018).

2 Model

The role of the model is to provide testable empirical hypotheses that we will verify in Section 3. We consider a stylised one-period economy of which we sketch the key features first. We focus on the type-of-employment choice and associated risks, and allow firms to provide insurance. Hence, our economy is inhabited by three types of agents - consumers, workers and firms - and there are two markets: the goods market and the labour market.

Workers face a choice between self-employment and payroll-employment. When a worker chooses to become self-employed, he or she goes to the goods market directly, where he or she faces the risk of not being able to sell his or her production. If, on the other hand, a worker chooses to seek employment in a firm, he or she faces the risk of unemployment. Once hired, however, the employee is insured by the firm against the risk in the goods market.

The firms create an endogenously determined measure of vacancies and are able to offer insurance to employees by the virtue of their large size. We formalize this description and fill-in the relevant details below.

2.1 Model setup

Consumers Consumers live on a unit square $[0,1] \times [0,1]$ and make purchases in a perfectly competitive goods market which they enter freely. Their preferences over consumption q are captured by a strictly concave utility function $u(q)$. To acquire q_c units of their consumption good at prevailing price p, they pay with a spot good of their own production which is created according to a linear production function. Thus, given the market price p the expected utility of consumers choosing q_c reads:

$$V^B(q_c, p) = u(q_c) - pq_c.$$

The optimal demand q_c is therefore pinned down by the following equation:

$$u'(q_c) = p. \tag{1}$$

Note, as the total mass of buyers is equal to 1, this is also the aggregate demand equation.

[3] Our model is complementary to papers that explain self-employment from financing frictions (Buera, 2009, Evans and Jovanovic, 1989), because a frictional financial market could be introduced as an additional stage in the career choice game for those who choose self-employment.

Workers, Firms and Career Choice Workers live on a unit square $[0,1] \times [0,1]$ while firms live on a unit segment $[0,1]$. Workers value the spot good supplied by consumers and produce the consumption good q, but otherwise their preferences and production function are identical to those of the consumers. The workers face a career choice: they can either become a self-employed which yields expected utility V^{SE}, or they can enter the labour market which yields expected utility V^{LM}.[4] We provide more details below on how those are determined endogenously in equilibrium. Let $0 \leq SE \leq 1$ be the share of workers who become self-employed, then $A = 1 - SE$ is the measure of job applicants in the labour market hoping to find a job at a firm. Firms decide how many vacancies to open.

Labour Market There are search frictions in the labour market. The market is segmented into sub-markets indexed with (i,j) corresponding to wage rate w_i paid and the level of effort l_j exerted by an employee. The total number of contacts between applicants searching for a job $A_{i,j}$ and vacancies $V_{i,j}$ in a sub-market is given by a matching function $M_{i,j} = M(A_{i,j}, V_{i,j})$ featuring constant returns to scale and satisfying standard assumptions.[5] Each firm h opens a measure of vacancies $v^h_{i,j}$ in submarket at a cost of k per vacancy. The overall stock of vacancies in a sub-market (i,j) is $V_{i,j} = \int_0^1 v^h_{i,j} dh$. Let $\theta_{i,j} = \frac{V_{i,j}}{A_{i,j}}$ be the ratio of vacancies to applicants in a submarket. Each vacancy receives at most one applicant and this happens with probability $\zeta\left(\theta_{i,j}\right) = M_{i,j}/V_{i,j}$. Correspondingly, each applicant finds a job with probability $\mu\left(\theta_{i,j}\right) = M_{i,j}/A_{i,j}$.

Frictional Entry in the Goods Market Each self-employed worker and each employee that found a vacancy faces a frictional entry into the competitive goods market: only with probability λ can they enter and sell their production. We will also say that when a worker manages to enter the goods market, this worker is visible in the goods market. In the empirical section, we assume that λ depends positively on the penetration of high-speed Internet.[6]

Self-Employment We assume there is no insurance for the self-employed who do not manage to sell their production. Thus, the expected value of becoming self-employed and, upon making it to the goods market, supplying q_s, reads:

$$V^{SE}\left(p, q_s\right) = \lambda\left(u\left(pq_s\right) - q_s\right)$$

[4] We assume the choice to be exclusive. Since we focus on equilibria in which workers are indifferent, they could also divide their time if searching for a part-time job takes proportionally less job search effort. However, we rule out job search during self-employment, which is simply the extreme version of the assumption that running a viable business (that actually results in earnings) takes time and reduces search intensity.

[5] In particular, we assume M to be strictly concave in its arguments. The CRS assumption is made for tractability purposes only.

[6] Hence we assume that large firms and self-employed workers benefit equally from broadband penetration. However, we tend to think that large firms before the arrival of broadband Internet had smaller problems being visible to consumers than self-employed workers, so that the self-employed should benefit more from the arrival of broadband. However, throughout this paper we tie our hands and derive comparative statics for the case in which broadband Internet does not immediately result in a higher self-employment rate.

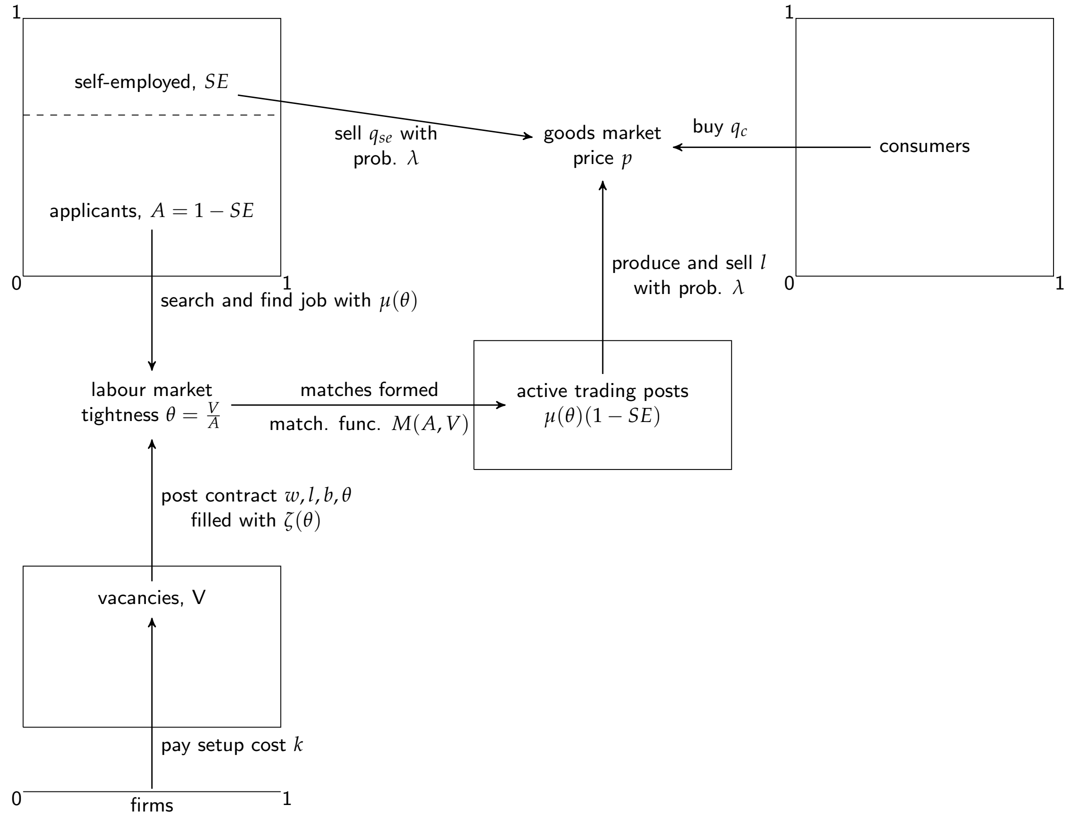

Figure 1: Snapshot of the model

with the optimal production choice q_s satisfying:

$$u'(pq_s) = \frac{1}{p} \tag{2}$$

Payroll Employment The law of large numbers applies, so that each firm receives expected profits. Therefore, an individual firm faces no uncertainty. As meetings are one-to-one, the firm cannot reshuffle applicants across its other vacancies. However, the firm can reshuffle the revenues and pay salaries to employees who were hired but didn't become visible in the goods market.[7] In the competitive search environment of the labour market, the expected value of going to a sub-market cannot be less than the market utility V^{LM}. Following the standard argument in such models with homogeneous workers and firms, there will be exactly one sub-market active and hence we scrap the (i, j) indexing. The optimal contract chooses (θ, w, l) to solve the constrained optimisation problem to maximize per-vacancy profit Π with respect to the market utility constraint V^{LM}:

$$\max_{\theta, w, l} \zeta(\theta)(\lambda p - w)\, l \equiv \Pi$$
$$\text{subject to: } \mu(\theta)(u(wl) - \lambda l) \geq V^{LM}.$$

[7] Note, the formulation below is derived in Appendix A as a solution to a more general contract posting problem.

Let $\phi = -\frac{\theta \zeta'(\theta)}{\zeta_l}$ be the constant elasticity of the vacancy-filling probability. The equilibrium contract in the labour market, given p, then satisfies the following conditions:

$$u'(wl) = \frac{1}{p}, \text{ and} \tag{3}$$

$$\phi(\lambda p - w) l = (1 - \phi) \frac{(u(wl) - \lambda l)}{u'(wl)}. \tag{4}$$

Furthermore, there is one sub-market with tightness $\theta = \frac{V}{A} = \frac{V}{1-SE}$. As there is free-entry of vacancies, firm profits per vacancy must be zero:

$$k = \zeta(\theta)(\lambda p - w) l. \tag{5}$$

Finally, the structure of the model is illustrated on Figure 1.

Equilibrium To close the model we formulate the goods market clearing condition and the career choice indifference condition for workers. The market clearing equilibrium price is defined implicitly as a price for which the aggregate demand equals the aggregate supply. Formally, the equilibrium concept we are after is a mixed-strategy solution to the career choice, one in which choosing each type of employment yields the same expected utility and workers randomize between them.

Definition 1 *A mixed strategy career equilibrium (MSCC-equilibrium) is a tuple* $(SE, p, q_s, q_c, w, l, \theta)$ *such that:*

- $0 < SE < 1$, $0 < \theta$, *both types of employment are chosen in equilibrium and active in the goods market*[8]
- *given* SE *and* p, *each consumer demands* q_c *as prescribed by equation* (1), *each self-employed sells* q_s *given by equation* (2) *and* V, θ, w, l *satisfy equations* (3) - (5) *given* p
- *price* p *clears the goods market:*

$$\lambda(SEq_s + (1 - SE)\mu(\theta)l) = q_c, \tag{6}$$

- SE *is chosen such that given all other conditions, workers are indifferent in equilibrium between self-employment and searching for a job at a firm:*

$$V^{SE} = \lambda(u(pq_s) - q_s) = \mu(\theta)(u(wl) - \lambda l) = V^{LM}. \tag{7}$$

The equilibrium is a vector consisting of 7 variables that jointly solve equations (1) - (7). In an MSCC-equilibrium workers are indifferent between the two careers and randomize over them. The endogenously determined self-employment rate SE is the weight assigned to self-employment in this randomisation.

[8] Note, with $V = 0$ there would be no payroll employment.

It is possible that no such mixed-strategy exists and there is either no self- or payroll-employment. We will refer to such cases as *corner equilibria*. The proof-of-existence theorem of an MSCC-equilibrium indicates when corner equilibria occur. However, our focus is on the empirically relevant case in which both types of employment are being chosen by workers.

2.2 Analytical results

We proceed to describing the MSCC-equilibrium of our model. We start with simple analytical observations assuming an equilibrium exists. Then, we argue when and how an MSCC-equilibrium can be constructed. Finally, we derive some comparative statics which will guide our empirical analysis.

Lemma 1 *Let $(SE, p, q_s, q_c, w, l, \theta)$ be an MSCC-equilibrium. Then:*

1. $wl = pq_s$, $w < p$ *and* $q_s > l$,
2. *There exists a continuous, differentiable and strictly increasing function $\psi(p)$ The career-choice indifference reads:*

$$V^{SE} = \lambda\psi(p) = \mu(\theta)\phi\psi(p) = V^{LM}$$

and the free-entry condition becomes:

$$k = \zeta(\theta)\,(1-\phi)\,p\psi(p)$$

The proof is provided in Appendix A.2. These results have an intuitive economic interpretation. Even though labour income in equilibrium is equalized between the two careers, the employees who are hired by a visible vacancy work more than the self-employed. This happens because those employees must generate profits to cover the vacancy set-up cost, and pay for the insurance against the goods market risk that all employees obtain.[9] Furthermore, as $\phi < 1$, we have $\lambda < \mu(\theta)$. Thus, obtaining income when pursuing a career in a firm is more likely than in self-employment. Our model therefore endogenously generates risk differentials in labour income between self-employed and payroll-employed workers.

Furthermore, Lemma 1 illustrates how the structure of the model simplifies, and allows us to reduce the dimensionality of the problem of finding an equilibrium. The career-choice indifference condition $\lambda = \mu(\theta)\phi$ means that labour market tightness is fully pinned down by λ and exogenous parameters of the matching function M. Secondly, the free entry condition pins down the price p for a particular value of k given already determined θ. Quantities q_c and q_s follow directly from p by the virtue of equations (1) and (2). w and l are linked with each other and p by $wl = pq_s$. We use this relationship to substitute one with the other in equation (4). Finally, SE comes out of the goods market clearing equation. For a given value of θ and p

[9] One can be concerned about empirical evidence that the self-employed report working longer hours than payroll employees. Even if one is willing to assume that all of those reported hours are measured accurately and spent fully on work, we don't think data on hours is suited well to validate our theory. As we abstract from leisure in the model, it is more natural to think about q_s and l in terms of production, which we generate with one single production function for firms and the self-employed. Therefore, the inequality $l > q_s$ only means that production per visible worker is larger (therefore, the model predicts employees to be more productive than self-employed) and the disutility of payroll employment is higher.

there can be at most one value of the self-employment rate which clears the goods market. To see why this is the case, note that given all other variables, the choice of q_{se} and l is fixed and the quantity supplied strictly increases in SE. We formalize this intuition in the proof of the following theorem. The proof is provided in Appendix A.3.

Theorem 1 (MSCC-equilibrium existence) *Let $\Lambda = (0, \sup_\theta \mu(\theta)\phi)$. Then, $\forall \lambda \in \Lambda$ there exist numbers $\underline{k}(\lambda)$ and $\overline{k}(\lambda)$, $\overline{k}(\lambda) > \underline{k}(\lambda)$ such that $\forall k \in \left(\underline{k}(\lambda), \overline{k}(\lambda)\right)$ an MSCC equilibrium exists and is unique.*

Testable empirical hypotheses First we focus on the career-choice indifference condition. The job finding rate $\mu(\theta)$ can be written as a product of a general matching efficiency E and a concave increasing function of market tightness $f(\theta)$. Assuming that both the catch-all λ parameter and the general matching efficiency E in the labour market depend positively on the penetration of high-speed Internet, the following lemma summarizes the effects of broadband Internet on our model economy.

Lemma 2 (Comparative statics) *Let $\mu(\theta) = Ef(\theta)$, f strictly concave and strictly increasing. For any MSCC-equilibrium the following hold:*

$$\frac{\partial SE}{\partial \lambda} > 0, \quad \frac{\partial SE}{\partial E} < 0, \frac{\partial \mu(\theta)}{\partial \lambda} > 0, \frac{\partial SE}{\partial k} > 0 \text{ and } \frac{\partial \mu(\theta)}{\partial E} = 0.$$

The proof is provided in Appendix A.4. These derivatives convey information about the drivers of the equilibrium composition of employment. An increase in λ directly increases the mass of workers visible in the goods market, which is further amplified by an increase in the job finding probability compatible with workers' career-choice indifference condition. This exerts downward pressure on the equilibrium price p, which can only be countered by an increase in the self-employment rate. As $q_s < l$, a higher self-employment rate lowers overall supply. In fact, what we have derived is that the impact of this composition-of-employment effect on p more than offsets the direct effect of λ.

Conversely, when labour market efficiency E increases, this is algebraically equivalent to a decrease in λ in the career-choice indifference condition. Naturally, the self-employment rate must fall. Interestingly, for the equilibrium job finding probability $\mu(\theta)$ to increase, λ must increase too. Any other changes will not affect $\mu(\theta)$. The equilibrium adjusts via changes in the composition of employment, but for a given measure of applicants A, their likelihood of securing a job at a firm is fully determined by λ. Thus, labour market conditions track the goods market conditions. Therefore, our model explains why job finding rates may show no trend even though matching efficiency may improve, as long as self-employment rates fall along the way. Allowing for self-employment as an alternative labour market state next to payroll employment and unemployment, is therefore a complementary solution to the puzzle identified in Martellini and Menzio (2018).

From the free entry condition it follows that for a fixed tightness θ the equilibrium price p is increasing in vacancy setup cost k. Thus, here again it is only an increase in the self-employment rate that can be consistent with an increase in market price p. Thus, we have the

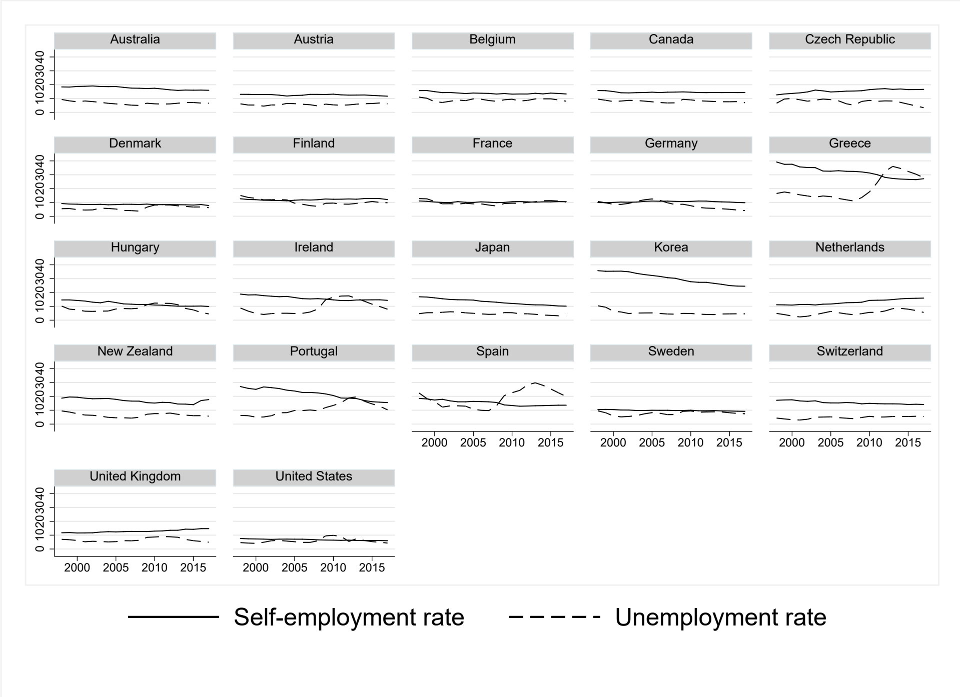

Figure 2: Self-employment and unemployment rates for 22 countries between 1998 and 2017.

self-employment rate increasing in k. We have concluded that increases in both λ and k increase the equilibrium self-employment rate. Changes in those two exogenous parameters can be thought of as *pull* and, respectively, *push* motives of selection into self-employment.

Summing up, the impact of Internet on the economy is fully identified by the response of the self-employment rate. What matters for the composition of employment, is which of the two reductions in matching frictions is stronger. If the reduction in matching frictions in the labour market dominates that in the goods market, the self-employment rate will *decrease*, whereas the converse is true if Internet reduces frictions in the goods market relatively more.

3 Empirical Results

3.1 Estimation Procedure

Guided by the theoretical model set up in the previous section, we now turn to testing its predictions in the cross-country data. Our theoretical predictions concerning SE map directly into hypotheses about the self-employment rate defined as the number of self-employed workers over the labor force. Our theoretical predictions concerning tightness θ and the job finding rate $\mu(\theta)$ map one-to-one into the ratio of the number of unemployed over the sum of unemployed and payroll employees. For simplicity, we will refer to this variable as the unemployment rate, but we stress that the denominator excludes self-employed workers from the labor force that is used in the conventional denominator.

As our measure of reduction in market frictions or increase of matching efficiency, we use broadband Internet penetration. High-speed Internet is a prime example of a general purpose technology that can transform the organization of economic activity (Harris, 1998, Helpman and Trajtenberg, 1998). General purpose technologies tend to be accompanied by 'innovational complementarities' that make their impact on the way economic activity is organized more profound than the introduction of more specific, marketable technologies (Bresnahan and Trajtenberg, 1995). High-speed Internet has been accompanied by the development and use of platforms and other apps that facilitate trade. We think of these innovations as increasing the likelihood that a seller can be found by a customer. Because broadband Internet penetration measures the extent to which customers and the self-employed have access to these technologies, we use it as proxy for λ.[10] Internet also facilitates conventional job search and recruiting (Autor, 2001, Stevenson, 2009). It has reduced both the costs of job applications and the costs of screening each application. Although the interaction of these cost reductions is not unambiguous (see e.g. Albrecht et al. (2006)), there is some evidence of increases in matching efficiency (Martellini and Menzio, 2018). We therefore use broadband penetration as a proxy for E as well.

Switching careers may take time. To allow the effects of the reductions in frictions to be distributed over time, we follow the literature (Parker, 2004, Robson and Wren, 1999) and specify a generalized error-correction model

$$\Delta \ln y_{it} = \beta \Delta X_{it} + \omega X_{it-1} - \gamma \ln y_{it} + \alpha_i + \psi_t + \varepsilon_{it}. \tag{8}$$

In this equation the dependent variable is the difference of the logarithm of either the self-employment or the unemployment rate. On the right hand side we have country and time fixed effect variables α_i and ψ_t, respectively. These control for country-specific invariant characteristics, e.g. cultural attitudes to entrepreneurship or social stigma of unemployment, and for common time variation, e.g. the global business cycle. X_{it} denotes a list of regressors, in which the broadband penetration rate is the main variable of interest. Following the logic of an error-correction model, the β coefficients estimate the short-run effects of X_{it} on the dependent variable, while the ratios $\omega/|\gamma|$ measure the long-run effects.

Our model is very stylised. It focuses on the search frictions that create labour income risk and on how Internet diffusion reduces those frictions. As such, it abstracts from several important variables that have been found in previous work to impact cross-country self-employment rates. Because omitting such factors would likely bias our results, we incorporate four additional regressors in our analysis. First, we control for the natural logarithm of GDP per capita. The earlier literature finds a negative relationship between the general level of economic development, proxied with GDP per capita, and the self-employment rate (Acs et al., 1994, Poschke, 2018). Fluctuations in GDP are also likely to have an effect of unemployment rates. Moreover, Poschke (2018) shows that our redefined unemployment rate decreases with development, even though the conventional unemployment rate may increase with development (Feng et al., 2018).

Second, we account for the generosity of the official unemployment insurance system. In particular, following Parker and Robson (2004), Staber and Bgenhold (1993), Torrini (2005) and Kumar (2012), we control for the replacement rate, defined as the ratio of the unemployment

[10] We do not only think of Internet increasing the likelihood that a seller is found by a customer, but also of Internet increasing the likelihood that a previously unknown seller is considered sufficiently trustworthy by a customer to do business. Although we do not model such mechanisms explicitly, we do believe that ratings and reviews on platforms have decreased asymmetric information and facilitated trade.

benefit to the median wage. The more generous the UI system, the more likely prospective workers are to engage in job search rather than self-employment. This can arise due to moral hazard problems which make monitoring search effort difficult. The large replacement rates should also have a negative impact on job creation, increasing unemployment rates.

Third, following Parker and Robson (2004), Robson and Wren (1999) and Torrini (2005), the choice to become a self-employed can also be driven by tax evasion. Therefore, the higher taxes are, the larger the self-employment rate is likely to be. We thus construct a variable referred to as tax burden, as the average of the tax wedge imposed on a single earner household and married couples with two children and single earner.

Finally, we introduce a variable that measure the share of public sector employment in total employment, which is shown to be relevant in Staber and Bgenhold (1993) and Torrini (2005). It proxies for the incidence of safe, stable jobs in the economy. Therefore, we expect that countries with big public sector employment exhibit less self-employment. The idea here is that even though firms in our model offer perfect insurance, in reality there are certain impediments for them to do so (e.g. moral hazard) and government jobs come with stability.

3.2 Data

We take the information to construct the *Self-employment* and *Unemployment* rates from ILOSTAT (writing in italics the names of variables that will later appear in tables). Figure 2 presents the evolution of these variables between 1998 and 2017 for the 22 OECD countries for which we have information on broadband Internet as well. We see that in all countries self-employment is either flat or decreasing, except for the Czech Republic, Netherlands, and United Kingdom. Unemployment is more volatile, especially in the countries struck most heavily by the Eurocrisis. The message across countries is more mixed, but on average there is no evidence for a decreasing trend in unemployment rates. These observations are confirmed in Table 1, which presents the average level and average annual change (first differences) of these variables for each country.

The broadband penetration rate is defined as the number of broadband subscribers per 100 inhabitants.[11] We take these data from the ITU World Telecommunication/ICT Indicators Database, in which broadband Internet appears in 1998 (in seven countries only, with each less than 0.5% penetration). To control for potential endogeneity, which could arise if an increase in gig-economy self-employment would prompt further investment in broadband technology, we follow the instrumental variable approach introduced in Czernich et al. (2011). The idea behind this instrument is that the most commonly used broadband standards use pre-existing infrastructure to connect homes and small- and medium-sized firms to the larger network. In particular, the copper wire of the voice telephony network and the coaxial cable of the cable TV network are employed to connect individual users to the Internet. Since the voice telephony and cable TV network have been built for other purposes than broadband Internet, they provide valid instruments for broadband penetration.

[11] Broadband Internet offers download speeds of at least 256 kbit/s.

Table 1: Average level and average annual change (first differences) in the self-employment rate, unemployment rate, and regressors

	Self-employment		Unemployment		Pred. broadband		GDP		Replacement Rate		Tax Burden		Public Sector	
	Level	Change	Level	Change	Level	Change	Level	Change	Level	Change	Level	Change	Level	Change
Australia	17.51	-0.13	6.83	-0.14	18.96	1.60	41.57	0.59	58.44	-0.13	22.68	-0.15	31.65	0.36
Austria	12.59	-0.07	5.72	0.00	18.49	1.56	40.84	0.46	60.06	-0.19	42.57	0.06	28.65	0.17
Belgium	13.95	-0.13	8.97	-0.16	21.15	1.78	38.89	0.41	79.63	0.13	48.27	-0.22	39.22	0.17
Canada	14.57	-0.08	8.07	-0.14	23.70	2.00	39.74	0.48	58.87	0.13	24.82	-0.43	36.40	0.11
Czech Republic	15.50	0.21	7.67	-0.17	14.66	1.24	25.82	0.65	57.75	-0.13	33.85	0.14	25.08	0.16
Denmark	8.51	-0.08	5.97	0.04	23.56	1.99	43.15	0.38	81.06	-0.06	32.00	-0.25	38.81	0.07
Finland	12.11	-0.03	10.43	-0.28	21.19	1.79	37.39	0.47	80.88	-0.06	41.10	-0.21	35.48	0.08
France	10.36	-0.03	9.92	-0.13	20.75	1.75	35.56	0.32	84.38	-0.06	45.59	-0.14	37.77	0.06
Germany	10.47	-0.01	8.29	-0.35	21.48	1.81	39.10	0.52	91.50	-0.19	42.73	-0.12	31.36	0.07
Greece	31.96	-0.63	20.43	0.60	18.97	1.60	26.32	0.06	66.94	0.19	40.94	0.01	36.25	0.05
Hungary	11.90	-0.25	8.51	-0.30	15.59	1.31	21.15	0.52	59.00	0.00	44.87	-0.62	29.00	-0.04
Ireland	15.93	-0.24	9.41	-0.05	18.18	1.53	46.25	1.74	65.63	-0.63	23.32	-0.19	31.10	0.23
Japan	13.25	-0.36	4.72	-0.10	18.42	1.55	34.93	0.30	52.13	0.00	27.58	0.10	24.74	0.03
Korea	30.32	-0.59	5.36	-0.30	19.25	1.62	27.61	0.98	51.00	0.13	18.50	0.32	24.97	0.34
Netherlands	13.08	0.25	5.34	0.04	23.29	1.96	43.75	0.51	80.19	-0.44	34.43	-0.02	34.02	-0.00
New Zealand	16.96	-0.05	6.46	-0.20	18.69	1.58	30.65	0.50	58.13	0.19	12.36	-0.25	31.09	0.10
Portugal	21.82	-0.61	10.91	0.21	16.60	1.40	26.55	0.19	99.38	-0.31	33.28	0.08	31.72	0.24
Spain	15.29	-0.26	18.70	-0.13	16.20	1.37	31.33	0.35	81.75	-0.31	36.36	0.06	30.96	0.21
Sweden	9.87	-0.07	7.74	-0.11	25.01	2.11	40.18	0.66	76.81	-0.44	42.53	-0.39	40.27	0.05
Switzerland	15.50	-0.16	4.70	0.06	25.05	2.11	51.21	0.49	91.06	0.00	16.39	-0.08	32.92	0.13
United Kingdom	12.85	0.16	6.57	-0.11	19.87	1.67	35.99	0.45	52.56	0.00	29.66	-0.09	35.82	0.29
United States	6.71	-0.08	5.93	-0.02	24.66	2.08	48.13	0.60	62.81	0.00	25.03	0.02	31.70	0.24
Average	15.05	-0.15	8.48	-0.08	20.17	1.70	36.64	0.53	70.54	-0.10	32.68	-0.11	32.73	0.14

Notes: GDP per capita in $1000. All other variables are reported in percentages (for levels) and in percentage points (for changes).

Instrument relevance has been shown by Czernich et al. (2011). They find that the adoption of broadband Internet is well-described by a logistic diffusion curve, where the pre-existing voice telephony and cable TV infrastructure places a bound on the maximum reach of the broadband network in a country. Broadband penetration for each country and year can then be predicted with a nonlinear regression, featuring the maximum reach, the speed, and the inflection point of the diffusion process as parameters. Moreover, Czernich et al. (2011) show that the pre-existing infrastructure of the cable TV and voice telephony networks has no predictive value for the penetration of mobile telephony and computers, two other technologies that have been widely adopted around the same time as broadband Internet. In this paper we merely extend their work to a longer time period, and the details of this exercise are reported in Appendix B. By using these time-invariant instruments, we extract the supply-driven component of time-varying broadband that is free from demand-side effects based on the composition of employment, changes in aggregate income coming from variation in the unemployment rate, or policy-induced effects. This procedure yields a new variable, the *Predicted Broadband* penetration rate. Table 1 shows that the average predicted broadband penetration rates (and thus annual changes) differ substantially across countries.

We take information about the other regressors – *GDP* per capita, the *Replacement Rate*, the *Tax Burden*, and the size of the *Public Sector* – from the OECD. Unfortunately, the replacement rate is only available from 2001 onwards, and the tax burden from 2000. Adopting those control variables therefore slightly reduces the sample period. Looking at Table 1 again, we see that replacement rates and tax burdens differ substantially across countries, but that both on average are decreasing. The size of the public sector is more homogeneous, and increasing in almost all countries.

3.3 Results

We investigate equation (8) in several steps, varying the contents of the X_{it} matrix. Including the *GDP* variable is indispensable as our model abstracts from business cycles. Together with our main variable of interest, *Predicted Broadband*, we always employ *GDP* in our regressions. Then, we add the institutional variables one by one and finally, we estimate the model with all regressors. Since the data on institutional variables provided by the OECD usually start two to three years later than our data on broadband, there is trade-off between the length of the sample and the number of regressors we use. There is therefore value in displaying the results of various X_{it} compositions, and along the way, we hope to better understand the robustness of impact of Internet on the gig economy. We report the results of the fixed effects (FE) estimation in Table 2. Several insights emerge.

First, the signs of the coefficients on differenced and lagged *Predicted Broadband* are positive. This is in line with our model predictions when the reduction of goods market frictions is the dominant effect of Internet. We find evidence of both short- and long-term effects, but only the long-term effects remain significant when we introduce the *Replacement Rate* in the regression. In those instances that the coefficients on *Predicted Broadband* shrink, we also estimate these coefficients with smaller precision. This is because the OECD data on *Replacement Rates* are only available from 2001 onwards, so that we lose approximately one-fifth of the sample.

Table 2: Effects of Broadband Internet on Self-Employment: FE estimator

	(1) Δ SE Rate	(2) Δ SE Rate	(3) Δ SE Rate	(4) Δ SE Rate	(5) Δ SE Rate
Δ Predicted B-band	0.0182***	0.0128	0.0237***	0.0191***	0.0125
	(0.0065)	(0.0083)	(0.0068)	(0.0072)	(0.0078)
Lagged Predicted B-band	0.0024***	0.0020**	0.0033***	0.0024***	0.0017*
	(0.0008)	(0.0009)	(0.0011)	(0.0009)	(0.0009)
Δ GDP	-0.0003	-0.0007	0.0001	-0.0006	-0.0008
	(0.0017)	(0.0018)	(0.0016)	(0.0016)	(0.0018)
Lagged GDP	-0.0001	0.0001	0.0004	-0.0001	-0.0000
	(0.0008)	(0.0007)	(0.0009)	(0.0008)	(0.0008)
Δ Replacement Rate		-0.0009**			-0.0009**
		(0.0004)			(0.0004)
Lagged Replacement Rate		-0.0011***			-0.0011***
		(0.0003)			(0.0003)
Δ Tax Burden			0.0011		0.0027*
			(0.0017)		(0.0015)
Lagged Tax Burden			-0.0006		0.0002
			(0.0010)		(0.0012)
Δ Public Sector				-0.0020	-0.0031*
				(0.0015)	(0.0017)
Lagged Public Sector				-0.0005	-0.0010
				(0.0013)	(0.0015)
Lagged SE Rate	-0.0617***	-0.0923***	-0.0796***	-0.0650***	-0.0960***
	(0.0215)	(0.0286)	(0.0234)	(0.0220)	(0.0312)
Observations	418	350	374	408	343
No. countries	22	22	22	22	22
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
R^2 within	0.09	0.11	0.10	0.09	0.13
R^2 between	0.11	0.16	0.11	0.11	0.12
AR(1) test p-value	0.50	0.80	0.63	0.58	0.90
AR(1) coefficient	0.04	0.02	0.02	0.03	0.00

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Notes: The sample is 22 OECD countries for years 1998 - 2017. The dependent variable is the difference of the logarithm of *Self-Employment*.

The long-term effects are not only statistically significant, but also quite substantial. Recall that the long-term effect in (8) is given by $\omega/|\gamma|$, so that an increase from a 0 to 41.5% broadband penetration rate (the average predicted rate at the end of our sample, where broadband penetration has flattened off) ceteris paribus results in a doubling of the self-employment rate in the long run. We will get back to the size of this effect later in this section, when we consider the evolution of self-employment in the absence of broadband Internet.

Second, there is strong evidence, encapsulated by negative and significant coefficients on the *Replacement Rate*, that countries with a more generous UI system have lower self-employment rates. The sizes of these coefficients are remarkably stable. Negative effects are consistent with

Table 3: Effects of Broadband Internet on Self-Employment: FD estimator

	(1) Δ SE Rate	(2) Δ SE Rate	(3) Δ SE Rate	(4) Δ SE Rate	(5) Δ SE Rate
Δ Predicted B-band	-0.0130	-0.0077	-0.0017	-0.0100	-0.0065
	(0.0231)	(0.0252)	(0.0235)	(0.0235)	(0.0254)
Lagged Predicted B-band	0.0111**	0.0114**	0.0125***	0.0106**	0.0108**
	(0.0046)	(0.0048)	(0.0046)	(0.0047)	(0.0048)
Δ GDP	-0.0000	-0.0008	-0.0003	-0.0002	-0.0009
	(0.0021)	(0.0021)	(0.0021)	(0.0021)	(0.0021)
Lagged GDP	-0.0003	-0.0000	0.0001	-0.0008	-0.0005
	(0.0023)	(0.0023)	(0.0022)	(0.0023)	(0.0023)
Δ Replacement Rate		-0.0007			-0.0007
		(0.0005)			(0.0005)
Lagged Replacement Rate		-0.0017**			-0.0017**
		(0.0007)			(0.0007)
Δ Tax Burden			0.0024		0.0029*
			(0.0016)		(0.0017)
Lagged Tax Burden			0.0008		0.0014
			(0.0022)		(0.0023)
Δ Public Sector				-0.0024	-0.0026
				(0.0019)	(0.0020)
Lagged Public Sector				-0.0036	-0.0037
				(0.0030)	(0.0031)
Lagged SE Rate	-0.8348***	-0.8417***	-0.8490***	-0.8412***	-0.8497***
	(0.0763)	(0.0811)	(0.0762)	(0.0776)	(0.0823)
Observations	374	328	352	363	320
No. countries	22	22	22	22	22
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No
R^2 within	0.02	0.02	0.01	0.01	0.02
R^2 between	0.01	0.01	0.01	0.01	0.01
AR(1) p-value	0.00	0.00	0.00	0.00	0.00
AR(1) coefficient	-0.60	-0.58	-0.59	-0.58	-0.61

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Notes: The sample is 22 OECD countries for years 1998 - 2017. The dependent variable is the difference of the logarithm of *Self-Employment*.

a scenario in which workers who could potentially enter self-employment, decide to rely on unemployment benefits instead.

Third, *GDP* per capita is not relevant for our self-employment variable, neither in the short nor in the long run. This is in contrast to the frequently found result in cross-country data that GDP per capita affects self-employment rates negatively. The difference is likely to come from two sources. First, we have a different definition of the self-employment variable, which corresponds to the share of the self-employed in the active population, while other papers tend to look at the share of the self-employed in the employed population. Therefore, inclusion of unemployment in the denominator complicates the linkages between *GDP* and *Self-Employment*.

Table 4: Effects of Broadband Internet on Own Account Work: FE and FD estimators

	(1) Δ OA Rate	(2) Δ OA Rate	(3) Δ OA Rate	(4) Δ OA Rate
Δ Predicted B-band	0.0178	0.0170	-0.0074	-0.0058
	(0.0113)	(0.0113)	(0.0343)	(0.0351
Lagged Predicted B-band	0.0028**	0.0026*	0.0150**	0.0146**
	(0.0014)	(0.0015)	(0.0065)	(0.0066)
Δ GDP	-0.0049	-0.0051	-0.0048*	-0.0049*
	(0.0034)	(0.0033)	(0.0029)	(0.0029)
Lagged GDP	-0.0006	-0.0008	-0.0042	-0.0047
	(0.0010)	(0.0012)	(0.0031)	(0.0032)
Δ Replacement Rate	-0.0013***	-0.0012***	-0.0010	-0.0010
	(0.0004)	(0.0004)	(0.0006)	(0.0006)
Lagged Replacement Rate	-0.0014***	-0.0014***	-0.0023**	-0.0023**
	(0.0003)	(0.0003)	(0.0009)	(0.0009)
Δ Tax Burden		0.0022		0.0027
		(0.0019)		(0.0024)
Lagged Tax Burden		0.0011		0.0030
		(0.0018)		(0.0032)
Δ Public Sector		-0.0032		-0.0024
		(0.0026)		(0.0027)
Lagged Public Sector		-0.0007		-0.0042
		(0.0021)		(0.0043)
Lagged OA Rate	-0.1085***	-0.1111***	-0.8938***	-0.8965***
	(0.0367)	(0.0399)	(0.0834)	(0.0856)
Observations	350	343	328	320
No. countries	22	22	22	22
Year FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	No	No
R^2 within	0.12	0.13	0.01	0.01
R^2 between	0.007	0.06	0.01	0.01
AR(1) p-value	0.53	0.49	0.00	0.00
AR(1) coefficient	-0.04	-0.04	-0.58	-0.57

Standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Notes: The sample is 22 OECD countries for years 1998 - 2017. The dependent variable is the difference of the logarithm of *Own Account Work*. Columns (1) and (2) report FE estimation and columns (3) and (4) report FD estimation.

Second, our sample consists solely of developed economies while self-employment rates are usually found to be higher among developing countries.

Finally, in the richest regression specification we find evidence on *Tax Burden* and the size of *Public Sector* impacting self-employment rate in the short run.

We also perform tests on autocorrelation of the residuals for each specification, but cannot find any evidence in favour of it. Still, we estimate a first-differenced (FD) version of equation (8) that relies on weaker assumptions on the error term. This procedure removes the unobserved fixed effects α_i at the cost of shrinking the length of the sample. We follow the Andersen-Hsiao approach and instrument the lagged dependent variable and *GDP* per capita with its previous observations. We report the results of this procedure in Table 3. There, only the long run effects of *Predicted Broadband* and the *Replacement Rate* are significant with the same signs and interpretation as in the case of the FE estimator. The coefficient on the differenced *Tax Burden* is positive, in line with the theory proposed by Torrini (2005). In the short run, increases in tax rates may thus prompt workers to register as self-employed to evade higher payroll taxes.

3.4 Quantitative relevance and robustness

The motivation for the relevance of broadband Internet for self-employment rates partly depends on the development of innovational complementarities such as apps and platforms. If these innovations are part of the mechanism, one would expect the effect on the self-employment rate to be concentrated among own-account workers rather than self-employed employing other employees. Similarly, in our theoretical model, self-employment and payroll employment are polar opposites in terms of insurance against goods market risk. Employees receive full insurance while the self-employed bear all of the risk themselves. In reality, the ability to insure against goods market risk will differ among self-employed workers. An employer with two employees might not be able to smooth their income as much as larger firms can for their employees. However, such a self-employed is still more likely to insulate their income against business risk than an own-account worker. Therefore, we expect broadband Internet to have larger effects on own-account workers.

We now focus on the sets of regressors that include the *Replacement Rate* and estimate (8) for the *Own-Account Work* rate, defined as the ratio of the number of all own-account workers over the size of the active population. We report the results of this exercise in Table 4, with the FE estimator in the first two columns, and the FD estimator in the last two columns. Here, we confirm the positive effect of *Predicted Broadband* and the negative effect of *Replacement rate* on this more narrowly defined group of self-employed workers.

To better gauge the quantitative significance of our results and to be able to compare the effect sizes for self-employment and own-account work, we consider a counterfactual scenario of no broadband and compute predictions for both using our FE estimates with the richest set of regressors. We find that the introduction and diffusion of broadband halted three quarters of an otherwise pronounced decline in the self-employment rate, and virtually all of the decrease in the own-account work rate, as illustrated in Figure 3. We also see that the effect has flattened off with the saturation of the broadband diffusion process.

We find that the relative magnitude of broadband is stronger for own-account work than for self-employment. In 2017, the actual average self-employment rate stood at approximately 13.9% while in the absence of broadband it would have been 8.4%. For own-account work rate these numbers are 9.2% and 4.4% respectively. These results imply that because of broadband, an approximately additional 4.8% of the labor force has become own-account worker, while non-own-account self-employed workers contribute only an additional 0.7% of the labor force. Therefore, almost 90% of the effect of broadband on the self-employment rate is due to own-account workers, which is more than a proportional response as own-account workers in our sample constitute about 60% of total self-employment. Alternatively, without high-speed Internet, own-account work rates would drop by almost half, while for self-employment the

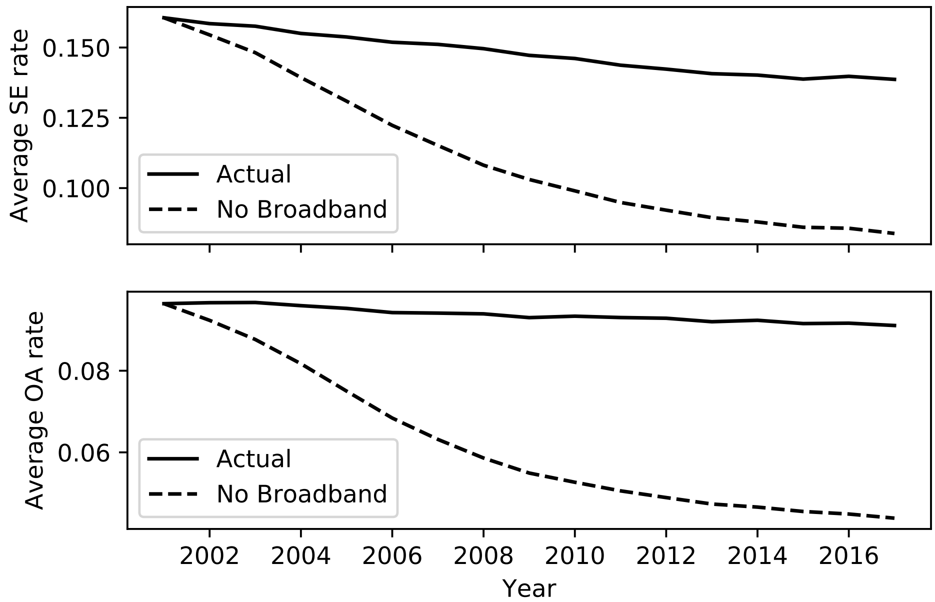

Figure 3: Averaged sample counterfactual predictions of no broadband development for self-employment (top) and own account work rates (bottom).

decline would be approximately equal to one-third.

Summing up, we find significant and substantial negative effects of broadband Internet on self-employment rates. Through the lens of our model, and more specifically Lemma 2, our findings imply that the reductions in goods market frictions dominate the reductions in labor market frictions. In this case, Lemma 2 also predicts that broadband Internet should reduce (redefined) unemployment rates. Our model has therefore an additional prediction that we will test.

Therefore, we conduct an exercise analogous to that reported in 4 with the redefined *Unemployment* rate as the dependent variable. The results of this exercise are reported in Table 5. Here we find further, but weaker, evidence in favour of the model. Only for the FE estimation in the first two columns we obtain significant estimates of the *Predicted Broadband* coefficients. Although the coefficient on the lagged *Predicted Broadband* rate is still negative, the removal of the fixed effects by first differencing comes at the cost of less precise estimates in columns (3) and (4) of this table.

However, the other parameter estimates suggest we should take the results in those two last columns with a grain of salt. In particular, the FE estimation provides evidence of fluctuations in *GDP* per capita being negatively correlated with unemployment, as predicted by Okun's Law. We don't have these coefficients significant in the first-differenced version of our estimation equation, even though we explicitly address potential endogeneity of *GDP* per capita by instrumenting it with its lags (together with the lagged *Unemployment* rate). However, the results for the *Replacement Rate* are sensible - more generous UI is associated with higher unemployment rates - and its coefficients and their precision are remarkably stable. This is because identification follows from substantial shifts in UI generosity following labour market

Table 5: Effects of Broadband Internet on Unemployment: FE and FD estimators

	(1) Δ U Rate	(2) Δ U Rate	(3) Δ U Rate	(4) Δ U Rate
Δ Predicted B-band	-0.1007**	-0.1129**	0.0228	-0.0021
	(0.0451)	(0.0505)	(0.1058)	(0.1063)
Lagged Predicted B-band	-0.0119**	-0.0100*	-0.0102	-0.0096
	(0.0057)	(0.0054)	(0.0185)	(0.0185)
Δ GDP	-0.0450**	-0.0443**	0.0436	0.0442
	(0.0180)	(0.0182)	(0.0947)	(0.1058)
Lagged GDP	-0.0066	-0.0059	0.0078	0.0117
	(0.0042)	(0.0045)	(0.0604)	(0.0679)
Δ Replacement Rate	0.0033*	0.0034*	0.0031*	0.0032*
	(0.0020)	(0.0019)	(0.0018)	(0.0018)
Lagged Replacement Rate	0.0033*	0.0029	0.0069**	0.0069**
	(0.0020)	(0.0019)	(0.0032)	(0.0033)
Δ Tax Burden		0.0012		-0.0010
		(0.0054)		(0.0065)
Lagged Tax Burden		0.0004		0.0045
		(0.0060)		(0.0090)
Δ Public Sector		0.0231***		0.0164**
		(0.0070)		(0.0074)
Lagged Public Sector		0.0162***		0.0192
		(0.0038)		(0.0129)
Lagged U Rate	-0.1073***	-0.1155***	-0.4969**	-0.4869**
	(0.0353)	(0.0318)	(0.1934)	(0.2146)
Observations	350	343	328	320
No. countries	22	22	22	22
Year FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	No	No
R^2 within	0.59	0.62	0.27	0.28
R^2 between	0.04	0.02	0.02	0.03
AR(1) p-value	0.00	0.00	0.00	0.00
AR(1) coefficient	0.26	0.22	-0.50	-0.49

Standard errors in parentheses, *$p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Notes: The sample is 22 OECD countries for years 1998 - 2017. The dependent variable is the difference of the logarithm of *Unemployment*. Columns (1) and (2) report FE estimation and columns (3) and (4) report FD estimation.

policy reforms. In such cases, the reforms normally yield a shift in the *Replacement Rate* which remains stable afterwards. Hence, the additional differencing does not affect this variable much. However, we stress that we take these results with a grain of salt. Not only because we have no significant effects for the FD estimator, but also because we find business cycle frequency shocks to be much more important for unemployment than for self-employment as is evident in Figure 2, while our theoretical model abstracts from them.

4 Conclusions

We derived a simple model of type-of-employment choice and applied it to understand the effects of the Internet on the so-called gig-economy. In our model, the composition of employment is driven by income risk and firms' ability to insure their employees against it. We show that a reduction in goods market frictions increases self-employment, even though firms benefit from such a reduction as well, because it decreases the value of insurance that firms offer.

We use our theory to disentangle the goods market and labour market effects of improvements in ICT technologies. Using cross-country data on the composition of employment and pre-existing infrastructure as instrument for broadband penetration, we find that the results confirm the general wisdom that access to fast Internet prompts more self-employment. Without the introduction of broadband Internet, the self-employment rate in our sample would fall by about one-third. The fact that this didn't happen is to a great extent driven by own-account work, the type of self-employment that is most exposed to income risk.

References

ABRAHAM, K. G., J. C. HALTIWANGER, K. SANDUSKY, AND J. R. SPLETZER (2018): "Measuring the Gig Economy: Current Knowledge and Open Issues," Discussion Paper 24950, National Bureau of Economic Research.

ACS, Z. J., D. B. AUDRETSCH, AND D. S. EVANS (1994): "Why Does the Self-Employment Rate Vary Across Countries and Over Time?" Discussion Paper 871, CEPR.

AKERMAN, A., I. GAARDER, AND M. MOGSTAD (2015): " The Skill Complementarity of Broadband Internet," *The Quarterly Journal of Economics*, 130, 1781–1824.

ALBRECHT, J., P. A. GAUTIER, AND S. VROMAN (2006): "Equilibrium Directed Search with Multiple Applications," *The Review of Economic Studies*, 73, 869–891.

AUDRETSCH, D. B., D. HEGER, AND T. VEITH (2015): "Infrastructure and entrepreneurship," *Small Business Economics*, 44, 219–230.

AUTOR, D. (2001): "Wiring the labor market," *Journal of Economic Perspectives*, 15, 25–40.

BLANCHFLOWER, D. G. (2000): "Self-employment in OECD countries," *Labour Economics*, 7, 471 – 505.

BLAU, D. (1987): "A Time-Series Analysis of Self-employment in the United States," *Journal of Political Economy*, 95, 445–67.

BRADLEY, J. (2016): "Self-employment in an equilibrium model of the labor market," *IZA Journal of Labor Economics*, 6, 1–30.

BRESNAHAN, T. F. AND M. TRAJTENBERG (1995): "General purpose technologies Engines of growth?" *Journal of Econometrics*, 65, 83 – 108.

BUERA, F. (2009): "A dynamic model of entrepreneurship with borrowing constraints: Theory and evidence," *Annals of Finance*, 5, 443–464.

CZERNICH, N., O. FALCK, T. KRETSCHMER, AND L. WOESSMANN (2011): "Broadband Infrastructure and Economic Growth," *The Economic Journal*, 121, 505–532.

DE MEZA, D. AND C. SOUTHEY (1996): "The Borrower's Curse: Optimism, Finance and Entrepreneurship," *Economic Journal*, 106, 375–86.

EVANS, D. AND B. JOVANOVIC (1989): "An estimated model of entrepreneurial choice under liquidity constraints," *Journal of Political Economy*, 808–827.

FAIRLIE, R. (2006): "The Personal Computer and Entrepreneurship," *Management Science*, 52, 187–203.

FENG, Y., D. LAGAKOS, AND J. E. RAUCH (2018): "Unemployment and Development," Discussion Paper 25171, NBER.

HARRIS, R. (1998): "The internet as a GPT: factor market implications," in *General Purpose Technologies and Economic Growth*, ed. by E. Helpman, Cambridge, MA: MIT Press, 145–166.

HELPMAN, E. AND M. TRAJTENBERG (1998): "Diffusion of general purpose technologies," in *General Purpose Technologies and Economic Growth*, ed. by E. Helpman, Cambridge, MA: MIT Press, 85–120.

HJORT, J. AND J. POULSEN (2019): "The Arrival of Fast Internet and Employment in Africa," *American Economic Review*, 109, 1032–79.

JOVANOVIC, B. (1982): "Selection and the Evolution of Industry," *Econometrica*, 50, 649–70.

KIHLSTROM, R. AND J.-J. LAFFONT (1979): "A General Equilibrium Entrepreneurial Theory of Firm Formation Based on Risk Aversion," *Journal of Political Economy*, 87, 719–48.

KOLKO, J. (2012): "Broadband and local growth," *Journal of Urban Economics*, 71, 100 – 113.

KRUEGER, A. (2000): "The internet is lowering the cost of advertising and searching for jobs," *New York Times*, C2.

KUMAR, A. (2012): "Self-employment, efficiency wage, and public policies," *Economic Inquiry*, 50, 1069–1079.

LUCAS, R. (1978): "On the Size Distribution of Business Firms," *Bell Journal of Economics*, 9, 508–523.

MARTELLINI, P. AND G. MENZIO (2018): "Declining Search Frictions, Unemployment and Growth," Discussion Paper 24518, National Bureau of Economic Research.

NARITA, R. (2019): "Self-employment in developing countries: A search-equilibrium approach," *Review of Economic Dynamics*, forthcoming.

PARKER, S. (2004): *The Economics of Self-Employment and Entrepreneurship*, Cambridge University Press.

PARKER, S. C. AND M. T. ROBSON (2004): "Explaining International Variations in Self-Employment: Evidence from a Panel of OECD Countries," *Southern Economic Journal*, 71, 287–301.

POSCHKE, M. (2013): "Who becomes an entrepreneur? Labor market prospects and occupational choice," *Journal of Economic Dynamics and Control*, 37, 693–710.

——— (2018): "Wage employment, unemployment and self-employment across countries," Working Paper F-32205-ETH-1, International Growth Centre.

RISSMAN, E. (2003): "Self-employment as an alternative to unemployment," Working Paper Series WP-03-34, Federal Reserve Bank of Chicago.

ROBSON, M. T. AND C. WREN (1999): "Marginal and Average Tax Rates and the Incentive for Self-Employment," *Southern Economic Journal*, 65, 757–773.

ROOSE, K. (2014): "Does Silicon Valley Have a Contract-Worker Problem?" *New York Magazine*.

RUD, J. P. AND I. TRAPEZNIKOVA (2018): "Job Creation and Wages in Least Developed Countries: Evidence from Sub-Saharan Africa," Mimeo.

STABER, U. AND D. BGENHOLD (1993): "Self-employment: a study of seventeen OECD countries," *Industrial Relations Journal*, 24, 126–137.

STEVENSON, B. (2009): "The internet and job search," in *Studies of Labour Market Intermediation*, ed. by D. Autor, Chicago, IL: University of Chicago Press, 67–88.

TORRINI, R. (2005): "Cross-country differences in self-employment rates: the role of institutions," *Labour Economics*, 12, 661 – 683.

VISSCHERS, L., A. MILLAN, AND M. KREDLER (2014): "Great opportunities or poor alternatives: self-employment, unemployment and paid employment over the business cycle," 2014 Meeting Paper 597, Society for Economic Dynamics.

A Proofs and Derivations

A.1 General contract posting problem

Here we will show that the constrained optimisation contract posting problem in the labour market is not imposed exogenously ex-ante but comes out as a solution to a more general problem. The firms can offer a general contract that will involve paying d when the vacancy is not visible in the goods market and will pay a wage rate w for effort l, posted in a sub-market with queue length θ. This contract solves:

$$\max_{l,\theta,w,d} \zeta(\theta)\left(\lambda(p-w)l-(1-\lambda)d\right) \equiv \Pi$$
$$\text{subject to: } \mu(\theta)\left(\lambda\left(u(wl)-l\right)+(1-\lambda)u(d)\right) \geq V^{LM}$$

The FOCs for this problem read, with χ being the multiplier on the market utility constraint:

$$\frac{\partial\Pi}{\partial\theta}: \quad \zeta'(\theta)\left(\lambda(p-w)l\right) = \chi\mu'(\theta)\left(\lambda\left(u(wl)-l\right)+(1-\lambda)u(d)\right) \tag{9}$$

$$\frac{\partial\Pi}{\partial l}: \quad \zeta(\theta)\lambda(p-w) = \chi\mu(\theta)\lambda\left(u'(wl)w-1\right) \tag{10}$$

$$\frac{\partial\Pi}{\partial w}: \quad -\zeta(\theta)\lambda l = \chi\mu(\theta)\lambda u'(wl)l \tag{11}$$

$$\frac{\partial\Pi}{\partial d}: \quad -\zeta(\theta)(1-\lambda) = \chi\mu(\theta)(1-\lambda)u'(d) \tag{12}$$

Let's have a closer look at equations (11) - (12), after canceling some terms they can be combined together to yield:

$$u'(d) = u'(wl) \text{ consumption smoothing.} \tag{13}$$

Hence, all employees receive identical consumption, but only those able to work exert effort l. d as a control is redundant as it's fully determined by optimal choices of w and l. Factoring in equation (13) we can simplify remaining FOCs a bit. Note, firm profits turn out to read:

$$\text{firm profit per vacancy} = \Pi = \zeta(\theta)(\lambda p - w)l$$

and equation the market utility constraint now reads:

$$\mu(\theta)\left(u(wl)-\lambda l\right) \geq V^{LM}$$

These two equations we consider in the main text. It's straightforward to derive that the remaining FOCs of the simplified problem coincide with the FOCs of this more general problem once b is replaced with wl. This is intuitive, as he visibility shock is publicly observable to the firm and the employee, risk-neutral firms find it optimal to fully insure risk-averse agents. Note, employees being atomistic from the point of view of the firm is not crucial for this result, however, it is a convenient assumption to make. An alternative would be to model a competitive credit market.

A.2 Proof of Lemma 1

Proof.

1. Here we show the results regarding the characteristics of the labour income distribution, namely: $wl = pq_s$, $w < p$ and $q_s < l$. Note, combining equations (2) and (3) we have:

$$u'(pq_s) = \frac{1}{p} = u'(wl) \implies wl = pq_s.$$

Next, for firms to make non-negative profits per vacancy it must hold $w < \lambda p \implies w < p$. The remaining part that $q_s < l$ follows trivially. This concludes the proof of the first part of the lemma.

2. For the second part of the lemma, concerned with function $\psi(p)$ we start with removing q_s in V^{SE}. From (2):

$$q_s = \frac{1}{p}\left[u'\right]^{-1}\left(\frac{1}{p}\right)$$

with $\left[u'\right]^{-1}(\cdot)$ being the inverse of marginal utility. Therefore, we have:

$$V^{SE} = \lambda\left(u(pq_s) - q_s\right) = \lambda\left(u\left(\left[u'\right]^{-1}\left(\frac{1}{p}\right)\right) - \frac{1}{p}\left[u'\right]^{-1}\left(\frac{1}{p}\right)\right),$$

hence, we have:

$$\psi(p) \equiv u\left(\left[u'\right]^{-1}\left(\frac{1}{p}\right)\right) - \frac{1}{p}\left[u'\right]^{-1}\left(\frac{1}{p}\right) = u(pq_s) - q_s,$$

and we have $V^{SE} = \lambda\psi(p)$. We shall now demonstrate that $\psi(p)$ shows up in V^{LM}. First, we incorporate (3) into (4) to arrive at:

$$\begin{aligned}\phi\left(\lambda p - w\right) l = (1-\phi)\, p\left(u(wl) - \lambda l\right) \implies \\ \lambda l = (1-\phi)\left(u(wl)\right) + \phi\frac{wl}{p}\end{aligned} \tag{14}$$

Hence, we can rewrite V^{LM} as follows:

$$\begin{aligned} V^{LM} &= \mu(\theta)\phi\left(u(wl) - \frac{wl}{p}\right) \\ \implies V^{LM} &= \mu(\theta)\phi\psi(p) \end{aligned} \tag{15}$$

where we used $wl = pq_s$ and $\frac{wl}{p} = q_s$. Thus, we have proved that in any MSCC-equilibrium $\lambda = \mu(\theta)\phi$ must hold. The last remaining part is to define $\gamma(p)$ and simplify the free-entry condition. Let's get back to the surplus splitting equation (14) and use equation (15) which has $(u(wl) - \lambda l) = \phi\psi(p)$:

$$\begin{aligned}&\phi\,(\lambda p - w)\,l = (1-\phi)\,p\,(u(wl) - \lambda l) = (1-\phi)\,p\phi\,(\psi(p)) \implies \\ &(\lambda p - w)\,l = (1-\phi)\,p\psi(p)\end{aligned}$$

Using this we can rewrite the free-entry condition:

$$k = \zeta(\theta)\,(1-\phi)\,p\psi(p).$$

3. Monotonicity of $\psi(p)$. Note, we have $\psi(p) = u(pq_s) - q_s$ and hence we have $\psi'(p) = u'(pq_s)q_s > 0$.[12] Therefore, $\psi(p)$ is increasing in p.

■

A.3 Proof of Theorem 1

Proof. Let's fix λ. This pins down θ. Then, for fixed θ and fixed p, we have fixed q_s and l. The aggregate supply function $q_{\text{supply}} = \lambda\,(SEq_s + (1-SE)\,\mu(\theta)l)$ is a strictly decreasing function of SE. Therefore, there exists at most one value of SE that clears the goods market given the aggregate demand $q_c(p)$.

This equilibrium relationship can also be presented as a standard *move of the supply curve*, larger values of the self-employment rate SE coincide with lower market clearing quantities and higher prices, see Figure 4. This defines a 1-1 mapping between p and SE. Let's write this mapping as $p = p(SE)$. Therefore, we shall set:

$$\underline{k}(\lambda) = \zeta(\theta(\lambda))\,(1-\phi)\,\underline{p}\psi(\underline{p}) \tag{16}$$

$$\overline{k}(\lambda) = \zeta(\theta(\lambda))\,(1-\phi)\,\overline{p}\psi(\overline{p}) \tag{17}$$

$$\text{where } \underline{p} = \lim_{SE \mapsto 0^+} p(SE) \text{ and } \overline{p} = \lim_{SE \mapsto 1^-} p(SE)$$

Note, this has a clear economic interpretation. In equilibrium, larger values of the vacancy posting cost coincide, ceteris paribus, with largers values of the self-employment rate.

■

A.4 Proof of Lemma 2

Proof. The proof relies on three equilibrium conditions (free entry condition, workers' indifference condition and the goods market clearing condition) and relationships they imply between p, θ and SE.

[12] As only the first order effect matters: $\psi'(p) = u'(pq_s)q_s + \frac{\partial q_s}{\partial p}\,(pu'(pq_s) - 1)$ and the second term is equal to zero in the optimum.

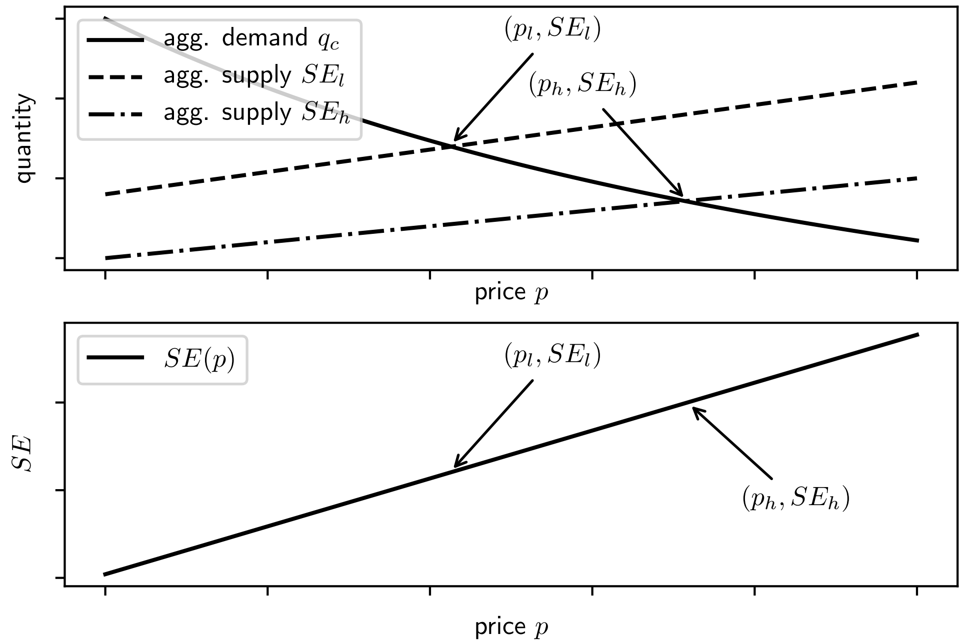

Figure 4: Relationship between SEself-employment rate and goods market clearing price p for fixed labour market tightness θ.

1. Effects of λ: implicitly differentiating the simplified career choice indifference condition we arrive at:
$$1 = \underbrace{\left[\mu'(\theta)\phi\right]}_{>0} \frac{\partial \theta}{\partial \lambda}$$
By standard properties, $\mu'(\theta) > 0$, hence the term in the squared bracket is indeed positive. Hence, this amounts to $\frac{\partial \mu(\theta)}{\partial \lambda} > 0$.

2. Next, we differentiate the free-entry condition:
$$0 = \underbrace{\left[\zeta'(\theta)\left(1-\phi\right)\right] \frac{\partial \theta}{\partial \lambda} \gamma(p)}_{<0} + \underbrace{\zeta(\theta)\left(1-\phi\right)\gamma'(p)}_{>0} \frac{\partial p}{\partial \lambda}$$
where we set $\gamma(p) = p\psi(p)$ for brevity. By standard properties, $\zeta'(\theta) < 0$ hence the first term is negative. By the virtue of Lemma 1, as $\gamma(p) = p\psi(p)$, $\gamma'(p) > 0$, thus, this equality can only hold if $\frac{\partial p}{\partial \lambda} > 0$.

3. Effects of k: from the simplified career choice indifference condition we immediately have $\frac{\partial \theta}{\partial k} = 0$ as λ does not depend on k. Now, from the free-entry condition:
$$1 = \underbrace{\zeta(\theta)\left(1-\phi(\theta)\right)\gamma'(p)}_{>0} \frac{\partial p}{\partial k}$$
where we used $\frac{\partial \theta}{\partial k} = 0$. Therefore, $\frac{\partial p}{\partial k} > 0$. The indifference condition of workers implies

$\frac{\partial\theta}{\partial k} = 0$, therefore $\frac{\partial SE}{\partial k} = \frac{\partial SE}{\partial p}\frac{\partial p}{\partial k} > 0$.

4. One can also write that:

$$\frac{\partial p}{\partial \lambda} = \frac{\partial p}{\partial SE}\frac{\partial SE}{\partial \lambda} + \frac{\partial p}{\partial \theta}\frac{\partial \theta}{\partial \lambda}$$

   The first component of the sum on the right hand side is the *composition of employment effect* on price induced by change of λ and the second component is the *reduction in unemployment effect* on price induced by change in λ. We have already established that $\frac{\partial p}{\partial SE} > 0$ and that $\frac{\partial \theta}{\partial \lambda} > 0$. Trivially, $\frac{\partial p}{\partial \theta} < 0$ therefore, for the signs to match it must be that $\frac{\partial SE}{\partial \lambda} > 0$.

5. Finally, the indifference conditon can be written as $\lambda = Ef(\theta)\phi$. Therefore, derivatives of θ, p and SE with respect to E will have their signs opposite to those of their counterpart derivatives with respect to λ. In particular, we have that for the workers' indifference condition $\frac{\partial \theta}{\partial E} < 0$ in order to exactly offset the increase in E to keep $\lambda = \phi\mu(\theta)$ satisfied for fixed λ. Then, this jointly implies that the job-filling rate $\zeta(\theta)$ goes up. Because of free entry of vacancies, the price p must fall and hence SE must go down.

■

B First-stage regression

In this section of the Appendix we present the results of the first-stage regression. This nonlinear regression relies on the fact that roll-out of broadband predominantly relied on the copper wire of the voice telephony network or the coaxial cable of the cable TV network, so that these pre-existing infrastructures provide information on the maximum attainable broadband penetration rate (Czernich et al., 2011). Since 1998 is the first year broadband appeared in our data, we take the voice telephony and cable TV penetration rates in 1997 as instruments for the maximum reach of broadband.[13] We take the values of these instruments from the OECD ICT Key Indicators. These values, as well as the potentially endogenous broadband penetration rate at the end our sample period, are presented for each country in Table 6.

To arrive at a predicted broadband penetration rate, we first assume that the maximum broadband penetration rate for each country i is described by:

$$\gamma_i = \gamma_0 + \alpha_1 \text{tel\_net}_{i,1997} + \alpha_2 \text{cable\_net}_{i,1997}, \tag{18}$$

where $\text{tel\_net}_{i,1997}$ and $\text{cable\_net}_{i,1997}$ are the voice telephony and cable TV penetration rates in 1997. These γ_i enter the logistic diffusion curves that we assume to predict the broadband penetration rates B for each country i in year t, according to:

$$B_{it} = \frac{\gamma_i}{1 + e^{-\beta(t-\tau)}} + \varepsilon_{it}. \tag{19}$$

In this equation, β and τ are the coefficients for the speed and inflection point of the diffusion process, and ε_{it} is an error term. Substituting (18) into (19), we can estimate a nonlinear first-

[13] Broadband was introduced in Canada in 1997, but we don't have cable TV penetration rates for 1996.

Table 6: Infrastructure penetration rates (in %)

	Cable TV, 1997	Voice Telephony, 1997	Broadband, 2017	Predicted broadband, 2017
Australia	3.1	51.2	32.4	31.4
Austria	29.8	45.7	28.7	30.6
Belgium	88.7	48.5	38.3	35.0
Canada	68.4	61.6	38.0	39.2
Czech Republic	16.2	32.0	29.6	24.3
Denmark	49.5	63.6	43.7	39.0
Finland	37.6	55.6	30.9	35.1
France	9.6	57.6	43.7	34.3
Germany	50.5	55.0	40.5	35.5
Greece	0.6	51.6	33.9	31.4
Hungary	44.6	31.9	30.5	25.8
Ireland	46.9	42.1	29.4	30.1
Japan	11.3	47.9	31.8	30.5
Korea	5.9	52.0	41.6	31.9
Netherlands	93.1	56.6	42.3	38.5
New Zealand	0.3	50.5	33.6	30.9
Portugal	9.2	40.8	34.6	27.5
Spain	3.9	39.9	31.6	26.8
Sweden	60.5	68.0	39.0	41.4
Switzerland	87.5	64.5	46.1	41.5
United Kingdom	9.7	54.0	39.3	32.9
United States	64.8	66.0	33.9	40.8
Average	36.0	51.7	36.1	41.5

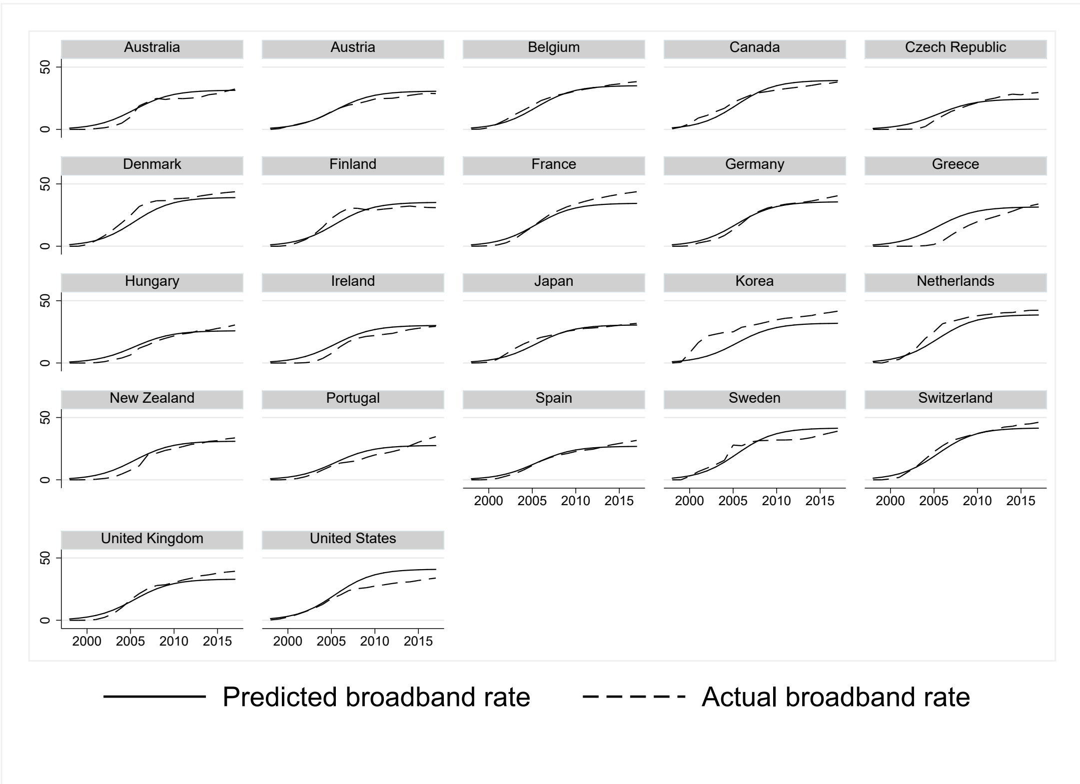

Figure 5: Actual and predicted broadband penetration rates for 22 countries, 1998–2017.

stage regression. The coefficients of this regression are reported in Table 7. The table shows that all coefficients are significant at the 1% level, and that the fit is very good. Compared to Czernich et al. (2011), nine additional years of data result in an even larger R^2, a slightly

Table 7: First-stage estimation results, 1998–2017.

	Actual broadband rate
γ_0	10.38***
	(1.566)
α_1	0.0555***
	(0.0105)
α_2	0.410***
	(0.0324)
β	0.458***
	(0.0224)
τ	2005.4***
	(0.127)
Observations	440
R^2	0.970

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

lower diffusion speed and an inflection point one year later. Cable TV has gained strength in predicting broadband, while the coefficient for voice telephony dropped.

We use the predicted values of this nonlinear first-stage regression in our second stage regressions. To illustrate the fit of the logistic diffusion curve, Figure 5 shows the actual and predicted broadband penetration rates for each country. The predicted broadband penetration rates in the last year of our sample are also reported in the last column of Table 6.