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Essays on the determinants of eco-innovation : evidence from French firms

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Spécialité SCIENCES ECONOMIQUES

Préparée au sein de l'Université de Caen Normandie

Essais sur les déterminants de l'éco-innovation : Une application aux entreprises françaises.

**Présentée et soutenue par
Malia KEDJAR**

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devant le jury composé de**

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« L'Université n'entend donner aucune approbation ni aucune improbation aux opinions émises dans les thèses. Ces opinions doivent être considérées comme propres à leurs auteurs »

A ma chère mère

A mon cher père

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Introduction générale

Motivation et contexte de la recherche

L'un des enjeux majeurs du 21^{ème} siècle est la lutte contre le changement climatique. L'activité humaine constitue un véritable danger pour l'environnement et en l'absence d'interventions fortes des décideurs politiques comme de la société civile, l'effet de serre provoquera un réchauffement climatique significatif au milieu du siècle (IPCC, 2019). Afin d'apporter des solutions à ce problème, il est nécessaire d'introduire des changements dans la façon de produire et de consommer, de ce fait, l'implication de l'ensemble des acteurs économiques (Individus, institutions, entreprises et États) est cruciale.

A l'échelle des États, plusieurs politiques ont été engagées au niveau européen et mondial afin de lutter contre la dégradation de l'environnement. Au niveau mondial, l'engagement des pays à réduire les émissions de gaz à effet de serre (GES) a été notamment matérialisé par la ratification du protocole de Kyoto¹ en 1997 puis par les Accords de Paris en 2015. Au niveau Européen, plusieurs initiatives ont été lancées comme par exemple la mise en place du paquet énergie climat à l'horizon 2020 et 2030. Le principal objectif étant de réduire les émissions de gaz à effet de serre de 20% à l'horizon 2020 et de 40% à l'horizon 2030 (par rapport aux niveaux de 1990). C'est ainsi qu'une loi sur la transition énergétique² a été mise en place en France qui, vise à baisser, à l'horizon 2030, de 40% les émissions de GES par rapport à l'année 1990 et de 30% la consommation d'énergies fossiles par rapport à 2012 et augmenter de 32 % la part des énergies renouvelables dans la consommation totale. A l'échelle des consommateurs, un rapport du centre de commerce international³ a indiqué qu'une demande toujours croissante de produits respectueux de l'environnement est observée (ITC, 2019). Face à ces défis environnementaux, pour un grand nombre d'entreprises, l'innovation est la clé pour continuer d'exister (Schumpeter, 1934). C'est un outil puissant qui peut être utilisé à la fois par les entreprises déjà implantées afin de renforcer leur compétitivité et par les nouvelles firmes pour faire face à la concurrence issue des entreprises déjà existantes sur le marché. L'innovation constitue ainsi un moyen pour améliorer la performance environnementale à la fois grâce à une plus grande efficacité énergétique, à une diminution des émissions de gaz à effet de serre au cours du processus de

¹ Il établit les engagements nécessaires pour éviter les impacts anthropiques (résultant de l'activité humaine).

²Cette loi peut être consultée à partir du lien suivant : <https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000031044385>

³ Cette étude a porté sur 5 pays européens : France, Allemagne, Italie, Pays-Bas et Espagne. Le rapport est accessible sur ce lien <https://www.intracen.org/publication/The-European-Union-market-for-sustainable-products/>

production et par l'offre de nouveaux produits «durables». L'accent est mis de plus en plus sur ce type d'innovations connues dans la littérature sous le nom de l'éco-innovations. Ces dernières deviennent ainsi des solutions majeures aux défis des entreprises (OCDE, 2010) en même temps qu'elles constituent un moteur primordial pour une croissance économique durable sur le long terme (OCDE, 2010; Smulders et al., 2014).

Délimitation des contours du concept de l'éco-innovation

L'éco-innovation est un concept récent, puisqu'il apparaît dans les années 1990. Plusieurs définitions ont été proposées dans la littérature et par des institutions nationales et internationales, ces définitions diffèrent sur plusieurs aspects mais elles s'accordent toutes sur le fait que la principale caractéristique de l'éco-innovation qui la différencie des autres types d'innovations, c'est sa contribution à la réduction des impacts environnementaux. Même si la définition de l'éco-innovation est encore en construction, il est possible de se référer à la définition la plus large de l'éco-innovation proposée par un rapport de la Commission européenne intitulé Measuring eco-innovation (Kemp and Pearson, 2007). Ce rapport définit l'éco-innovation comme suit :

« L'éco-innovation est la production, l'assimilation ou l'exploitation d'un produit, d'un procédé de production, d'un service, ou d'un outil managérial qui est nouveau pour l'organisation qui le développe ou l'adopte, et qui conduit, tout au long de son cycle de vie, à la réduction des risques environnementaux, de la pollution, et des autres impacts négatifs de l'utilisation de ressources (y compris de l'énergie) comparativement à d'autres alternatives pertinentes ».

Dans cette définition, une innovation ne nécessite pas d'être nouvelle sur le marché pour pouvoir être qualifiée d'éco-innovation, il suffit qu'elle soit nouvelle au niveau de la firme (cela concerne donc à la fois le développement et l'adoption de telles innovations). Cette définition inclut toutes les innovations qui sont bénéfiques pour l'environnement quelle que soit la motivation derrière leur développement ou leur adoption, en d'autres termes l'objectif environnemental n'est pas nécessaire a priori. Le champ de l'éco-innovation est ainsi élargi pour englober les innovations qui contribuent à l'amélioration de l'environnement de façon non intentionnelle. En effet, il existe des technologies dont la motivation principale n'est pas environnementale mais qui sont pourtant très bénéfiques pour l'environnement comme par exemple les vélos (Kemp et Arundel, 1998) et le télétravail (Djellal and Gallouj, 2009). C'est l'une des raisons qui rend la mesure de l'éco-innovation difficile. Par ailleurs, l'effet environnemental peut survenir non seulement pendant le processus de production mais aussi pendant toute la durée de vie d'un produit. En effet, il n'y a pas que la problématique de réduction de l'impact environnemental lors du processus de production d'un produit

qui doit être prise en compte, dans certains cas, l'utilisation d'un produit consomme plus d'énergie que ce qu'il a fallu pour le produire.

La complexité du terme éco-innovation a une double origine : d'une part l'utilisation de plusieurs termes pour un même concept ce qui engendre le développement de diverses définitions. Et d'autre part, l'utilisation de termes différents pour des concepts qui se rapprochent. En plus d'« éco-innovation », plusieurs concepts ont été utilisés dans la littérature et par les institutions publiques, notamment, « innovation environnementale », « technologies environnementales », « cleantech », « technologies propres »... De nombreux auteurs n'établissent aucune distinction entre les deux concepts « éco-innovation » et « innovation environnementale » et les utilisent indifféremment (Hellström, 2007; Ozusaglam, 2014). Dans cette thèse, nous ne ferons pas de distinction entre les deux concepts « éco-innovation » et « innovation environnementale » et nous utiliserons également le concept « technologies environnementales » pour désigner les éco-innovations technologiques.

Le concept d'éco-innovation ne doit pas être confondu avec le concept d'éco-conception qui est un sous ensemble de l'éco-innovation et qui se limite aux produits respectueux de l'environnement tout au long de leur cycle de vie (de la phase de production jusqu'à la fin de vie du produit).

L'éco-innovation peut être classée selon plusieurs critères. Diverses typologies ont été proposées dans la littérature. Elle peut être classée selon sa nature (classification inspirée du manuel d'Oslo (OCDE, 2005). L'éco-innovation peut donc être soit technologique soit organisationnelle. L'éco-innovation technologique se scinde en deux catégories : l'éco-innovation de produit et l'éco-innovation de procédé. L'éco-innovation de produit désigne l'introduction de produits et services nouveaux ou améliorés comme par exemple la peinture naturelle sans solvant. L'éco-innovation de procédé regroupe l'ensemble des technologies qui permettent de réduire la quantité d'input (matériaux et énergie) utilisée. Une éco-innovation est dite organisationnelle dans le cas d'introduction de nouvelles méthodes d'organisation.

L'éco-innovation ne se limite pas à l'éco-innovation technologique et organisationnelle mais elle englobe aussi l'éco-innovation sociale et institutionnelle (Carrillo-Hermosilla et al., 2010; Hazarika and Zhang, 2019; Rennings, 2000). Les éco-innovations sociales sont celles qui entraînent un changement dans les modes de vie et le comportement des consommateurs. L'éco-innovation institutionnelle se traduit par une création de réseaux locaux, la mise en place d'institutions environnementales internationales, une meilleure prise de décision incluant la participation des citoyens... (Merlin-Brogniart, 2017).

L'éco-innovation peut aussi être classée selon l'ampleur du changement qu'elle peut engendrer, elle est soit incrémentale soit radicale. On parle d'éco-innovation incrémentale lorsqu'elle est

incorporée à la fin d'un système de production. Elle permet de traiter en aval la pollution en la transformant en substances plus faciles à gérer. Elle n'introduit pas de changement significatif dans le processus de production. Les véhicules hybrides, les centrifuges, les épurateurs, les convertisseurs catalytiques, les équipements de désulfuration et les filtres constituent des exemples d'éco-innovations incrémentales. On parlera plutôt d'éco-innovation radicale dans le cas d'équipements et procédés totalement nouveaux qui provoquent un changement dans les modes de production, de consommation ou dans les modes de vie. Ces technologies permettent de réduire les émissions de polluants à la source et/ou d'utiliser des inputs moins polluants et/ ou d'utiliser moins de ressources. On peut citer à titre d'exemple les smart grids qui sont des réseaux électriques intelligents susceptibles de transformer de façon radicale la façon dont l'électricité est produite, distribuée et consommée.

Lorsqu'on considère la définition large de l'éco-innovation introduite par la Commission européenne, il est difficile de trouver un indicateur pour la mesurer. Comme pour les innovations classiques, les brevets et la recherche et développement sont parmi les indicateurs les plus utilisés pour mesurer l'éco-innovation. Les brevets représentent une mesure de l'output de l'éco-innovation. Ils reflètent généralement les éco-innovations intentionnelles c'est-à-dire celles qui ont pour objectif principal de réduire l'impact environnemental. Par ailleurs, le plus souvent ils reflètent les innovations nouvelles au marché et non pas les innovations nouvelles à la firme. L'utilisation de cet indicateur restreint donc sensiblement la définition de l'éco-innovation et réduit donc son poids. La recherche et développement (R&D) est un indicateur de l'input de l'innovation. Il reflète généralement l'éco-innovation technologique et la R&D formelle. D'autres indicateurs de mesure possibles ont été recensés mais ils sont moins utilisés en raison notamment de la difficulté d'accéder à ces données : des mesures directes de l'output de l'innovation comme par exemple le nombre d'innovations et les ventes des nouveaux produits ainsi que des mesures indirectes de l'impact de l'éco-innovation à travers l'étude de l'efficacité énergétique, ou encore le nombre et le type de publications scientifiques (Arundel and Kemp, 2009; OCDE, 2015).

Objectifs de la recherche

L'importance croissante accordée au rôle que peuvent jouer les entreprises dans l'introduction sur le marché de solutions contribuant à atteindre les objectifs du développement durable a conduit à l'intensification des recherches axées sur les déterminants de l'éco-innovation. La littérature sur cette question suggère que l'éco-innovation a une spécificité qui réside dans le fait qu'en plus de l'externalité de connaissance, elle génère aussi une externalité environnementale. Lorsqu'une entreprise adopte ou développe des éco-innovations, qui contribuent à réduire l'impact environnemental, elle supporte seule les coûts mais en fait bénéficier la société entière. Ainsi, l'éco-innovation évite une externalité négative et crée une externalité positive dont bénéficie l'ensemble de la population, elle engendre

généralement des gains publics plus élevés que les gains privés. Rennings (2000) parle d'un problème de double externalité et souligne que cette spécificité peut réduire l'incitation des entreprises à éco-innover, de ce fait, d'autres facteurs incitatifs sont importants afin de stimuler l'investissement des entreprises dans ce type d'innovation.

Malgré la grande avancée des travaux de recherche dans ce domaine, certains aspects requièrent encore une attention particulière. En effet, les difficultés inhérentes à la mesure des aspects environnementaux d'une innovation ont créé des contraintes pour une collecte de données précises et fiables. Ce qui a conduit les chercheurs à se limiter à certains aspects empiriques de l'éco-innovation à partir des données les plus aisément disponibles. De ce fait, une recherche empirique plus approfondie est nécessaire, et c'est précisément l'objectif de cette thèse. Plus généralement, l'objectif principal de ce travail est l'étude des facteurs qui influencent le développement des éco-innovations par les entreprises françaises. Nous essayons de remédier aux lacunes observées dans la littérature en adoptant trois approches complémentaires.

En premier lieu, nous avons constaté que la plupart des études empiriques se focalisent sur un seul aspect de la relation qui met en lien d'un côté, les facteurs incitant les entreprises à développer une éco-innovation notamment la réglementation environnementale et, d'un autre côté, l'effet que pourrait avoir l'éco-innovation sur la productivité. En nous basant sur l'hypothèse de Porter selon laquelle une politique environnementale bien conçue entraîne un résultat gagnant-gagnant, en d'autres termes, une réglementation environnementale combinée avec des stratégies d'innovation aura pour effet une protection de l'environnement et un gain de productivité (Porter, 1991; Porter and Van der Linde, 1995; Ramanathan et al., 2017; van Leeuwen and Mohnen, 2017), nous étudions à la fois les déterminants de l'éco-innovation et l'impact qu'elle peut engendrer sur l'activité de l'entreprise. Pour ce faire, nous construisons une base de données originale qui permet de remédier aux lacunes observées dans la littérature en termes d'information sur la R&D environnementale et la réglementation environnementale au niveau de l'entreprise.

Cette étude présentée dans le chapitre 1 est consacrée spécifiquement aux grandes entreprises. C'est pourquoi, dans un second temps, nous nous intéressons au cas des start-ups⁴. Selon un rapport du Ministère de la Transition Ecologique et Solidaire de 2020, 99,7% des entreprises françaises sont des Petites et Moyennes Entreprises⁵ (PME), parmi lesquelles une majorité de Très Petites entreprises

⁴ Deux principaux critères ont été retenus pour sélectionner les start-ups : avoir une activité d'innovation, qu'elle soit environnementale ou non, et l'âge de la start-up est inférieur à 12 années. L'échantillon constitué est composé à 79% de start-ups créées il y a moins de 5 ans.

⁵ Selon l'Insee les PME sont « des entreprises qui, d'une part, occupent moins de 250 personnes, d'autre part, ont un chiffre d'affaires annuel n'excédant pas 50 millions d'euros ».

(TPE) (3,67 millions). Les TPE et les PME occupent une place centrale dans l'activité économique étant donné leur part dans l'emploi salarié (46% des actifs) et leur part dans le chiffre d'affaires (elles produisent 1/3 du chiffre d'affaires total des entreprises françaises) (MTES, 2020). La politique publique en faveur du réchauffement climatique met l'accent sur le rôle que peuvent jouer ces TPE et PME dans le développement de l'éco-innovation (ADEME, 2018; EC, 2020; MTES, 2020). Au niveau européen, en 2014, un plan d'action en faveur de l'éco-innovation a été mis en place, il fournit une feuille de route pour soutenir les PME qui développent des éco-innovations. Au niveau français, un plan de la transition écologique des PME et TPE de 250 millions d'euros a été lancé, en juin 2020. L'objectif est d'aider les entreprises à intégrer l'environnement dans leur activité. Notamment à travers la mise en place de prêts verts garantis bonifiés et de prêts pour les économies d'énergies financés par l'ADEME. Par ailleurs, un label du coq vert pour identifier les entreprises vertes afin de promouvoir le partage d'expérience a été mis en place (MTES, 2020).

La littérature empirique souligne également que l'éco-innovation peut être développée à la fois par les PME et grandes entreprises, cependant les PME innovent différemment (Bos-Brouwers, 2009; Hansen and Klewitz, 2012). La singularité des PME se matérialise à la fois par leurs avantages et inconvénients. L'avantage le plus important des PME dans le contexte de l'innovation est la flexibilité qui se traduit par leur capacité à répondre rapidement aux demandes des clients et du marché. De plus, leur caractère entrepreneurial caractérisé par un rôle central du fondateur (qui est aussi souvent dirigeant) comme générateur d'idées. Les inconvénients des PME comprennent les contraintes en termes de ressources financières.

Nous avons pour but d'enrichir la littérature existante en considérant que les capacités entrepreneuriales jouent un rôle important dans la stimulation de l'éco-innovation. Dans ce contexte et afin d'orienter les politiques publiques, nous nous sommes intéressés aux start-ups éco-innovantes qui constituent un cas très peu étudié dans la littérature en raison principalement de la difficulté d'accès aux données. Pour remédier à ce problème, nous avons mené une enquête auprès des start-ups française, en 2019.

En troisième lieu, nous abordons l'un des aspects qui n'a pas été analysé dans la littérature, il s'agit des déterminants spatiaux de l'entrée des entreprises éco-innovantes. Cela représente donc un sujet d'investigation relativement nouveau dans ce domaine de recherche. Nous contribuons ainsi aux travaux étudiant le rôle que peut jouer les caractéristiques de la base de connaissances technologiques sur la création de nouvelles entreprises éco-innovantes. Nous construisons un ensemble d'indicateurs de connaissances technologiques spécifiques qui permettent de comprendre la recombinaison des technologies relatives aux innovations environnementales en France. Dans cet objectif, nous mobilisons un ensemble de données particulièrement riches et uniques basées sur des micro-données d'entreprises et des informations sur les brevets.

Pour répondre aux enjeux qui viennent d'être présentés, cette thèse est structurée en trois chapitres :

Chapitre 1 : Evaluation de la relation entre la recherche et développement (R&D), l'éco-innovation et la productivité : cas des entreprises françaises

Ce chapitre a pour objectif d'analyser à la fois les déterminants et les effets sur la productivité de l'éco-innovation. Les éco-innovations ont des caractéristiques spécifiques qui les distinguent des innovations classiques notamment le problème de la double externalité qui décrit une situation dans laquelle il est souvent difficile de rivaliser avec des concurrents qui ne sont pas engagés dans une démarche environnementale, car ils n'ont pas à internaliser les coûts sociétaux (comme la pollution par exemple). C'est pour cette raison que différents auteurs se sont intéressés à l'identification des acteurs spécifiques qui peuvent stimuler les entreprises à investir dans l'éco-innovation. Crépon, Duguet et Mairesse (1998) ont développé un modèle, connu dans la littérature sous le nom de modèle CDM, qui permet à la fois d'identifier les déterminants de l'input de l'éco-innovation (R&D) et de l'output de l'éco-innovation (brevets), ce modèle permet également d'étudier l'incidence de l'éco-innovation sur la productivité. Ce modèle a été largement utilisé dans la littérature sur l'innovation. Plus récemment, en raison de l'urgence de la problématique environnementale, il a fait l'objet d'adaptations au cas des éco-innovations (Marin, 2014; Marin and Lotti, 2017; van Leeuwen and Mohnen, 2017). Le modèle CDM a l'avantage de corriger les biais relatifs aux données sur l'innovation, notamment le biais de sélection et d'endogénéité.

En nous appuyant sur cette approche, le modèle que nous proposons dans ce chapitre est structuré en trois étapes. La première étape consiste à étudier la décision des entreprises à investir ou non dans la recherche et développement ; ensuite, dans le cas où elles choisissent d'entreprendre une activité de R&D, elles décident du montant à investir. Nous estimons plusieurs spécifications pour la recherche et développement notamment la R&D environnementale, la R&D non environnementale et la R&D totale. L'estimation est réalisée par la méthode en deux étapes de Heckman. La deuxième étape du modèle consiste à étudier le processus qui permet de passer de l'input de l'éco-innovation à l'output de l'éco-innovation (mesuré par les brevets environnementaux) et permet donc d'identifier les facteurs qui contribuent à l'aboutissement de l'activité de R&D. L'équation qui en résulte est estimée avec un modèle probit multivarié. La dernière étape consiste à étudier l'impact de l'éco-innovation sur la productivité. Nous estimons pour cette étape une fonction de production Cobb-Douglas augmentée d'une variable représentative de l'éco-innovation, mesurée par les brevets environnementaux.

Afin de prendre en compte l'ensemble des aspects nécessaires à cette étude et d'adopter une approche complète en analysant l'ensemble de la chaîne de causalité allant des déterminants de l'éco-innovation jusqu'à l'impact de cette dernière sur la productivité, nous nous sommes appuyés sur plusieurs bases de données. La base de données des brevets de l'OCDE (REGPAT) a été utilisée pour sélectionner l'ensemble des entreprises qui ont déposé au moins un brevet pendant la période d'étude auprès de l'Office Européen de Brevets (EPO). Les brevets environnementaux ont été sélectionnés en utilisant la classification coopérative des brevets⁶ (CPC). Les données obtenues ont été complétées par les données financières des entreprises issues de la base de données DIANE. En raison de l'absence d'identifiant commun entre les deux bases de données, nous utilisons le nom des entreprises et leur adresse pour les fusionner. Les noms et adresses des entreprises ne sont pas homogènes, il a été nécessaire de les homogénéiser puis les fusionner en utilisant un algorithme. Ensuite, nous avons intégré les données relatives à la recherche et développement, issues de l'enquête annuelle sur les moyens consacrés à la R&D dans les entreprises et les informations relatives à la réglementation environnementale, issues de l'enquête communautaire sur l'innovation en France (CIS). Nous avons obtenu un panel non cylindré qui contient les observations de 2 877 entreprises sur la période 2006–2014.

La principale contribution de ce chapitre est la constitution d'une base de données originale comportant des variables nécessaires pour l'étude de l'éco-innovation. Cela nous permet de remédier aux lacunes constatées dans la littérature sur les déterminants de l'éco-innovation : D'abord, en termes d'approche méthodologique en étudiant l'ensemble de la chaîne de causalité qui met en lien les déterminants de l'éco-innovation notamment la réglementation environnementale et l'éco-innovation, cela permet d'étudier dans un second temps le lien entre l'éco-innovation et la productivité. Ensuite, en termes de prise en compte de deux aspects : la réglementation environnementale au niveau microéconomique de l'entreprise et la R&D environnementale. De plus, nous supposons que les éco-innovations sont susceptibles de générer des effets hétérogènes sur la productivité selon leurs spécificités. De ce fait, nous considérons trois types d'éco-innovations : les technologies de traitement des déchets, les technologies d'énergie renouvelable et les technologies d'atténuation du changement climatique.

⁶ La classification coopérative des brevets (CPC) est le nouveau système de classification des brevets introduit depuis 2013 afin de normaliser les systèmes de classification de tous les principaux bureaux de brevets. Il s'agit d'une extension de la classification internationale des brevets (CIB), il en a résulté des classes et sous-classes beaucoup plus détaillées et mieux structurées, ce qui facilite et rend la sélection des brevets plus précise.

Chapitre 2 : Quels sont les déterminants de l'éco-innovation des startups françaises ?

Plusieurs études empiriques se sont intéressées à l'étude de l'amélioration des pratiques environnementales des entreprises existantes. Cependant, nous en savons bien peu sur la stratégie d'éco-innovation des start-ups naissantes. En effet, peu de travaux ont été consacrés à l'étude de ces problématiques dans le cas des start-ups naissantes. Les grandes entreprises ont l'avantage de disposer des ressources et du capital humain nécessaires pour mener à bien les activités de recherche et développement. En revanche, les startups sont caractérisées par une forte capacité d'introduction sur le marché d'innovations radicales (Demirel et al., 2019; Isaak, 1997) et elles font preuve de plus de flexibilité et d'adaptation aux changements qui surviennent dans leur activité (Aragón-Correa et al., 2008; Keskin et al., 2013). Elles ont donc un rôle primordial à jouer dans l'atteinte des objectifs de développement durable. Dans cette étude, nous remédions à cette lacune observée dans la littérature en nous penchant sur le cas des startups éco-innovantes.

Ce chapitre a pour double objectif, d'abord, d'étudier la spécificité des start-ups éco-innovantes comparées aux start-ups non éco-innovantes en se basant sur deux aspects : le capital humain et la politique environnementale. Ensuite, il vise à étudier la pluralité des profils parmi l'échantillon des start-ups éco-innovantes afin d'identifier les différents facteurs incitatifs à l'éco-innovation dans chaque catégorie de start-ups identifiée. Nous adoptons une approche similaire à celle des auteurs qui regroupent les déterminants de l'éco-innovation en facteurs internes et externes en se basant à la fois sur la théorie fondée sur les ressources et sur la théorie économique évolutionniste. Notre étude est basée sur la mise en œuvre de méthodes d'analyse de données multidimensionnelles. Dans un premier temps, nous avons utilisé un modèle décisionnel, à savoir une analyse discriminante (AD) sur notre échantillon de start-ups éco-innovantes et non éco-innovantes (Celeux and Nakache, 1994; Huberty, 1994). Ensuite, une classification hiérarchique ascendante (HAC) (Lebart et al., 2000; Saporta, 2006) est utilisée pour établir une typologie des start-ups éco-innovantes en fonction de leurs caractéristiques entrepreneuriales.

Les bases de données et les enquêtes existantes sur l'innovation ne permettent pas de disposer des informations nécessaires sur la stratégie d'éco-innovation et le financement des start-ups éco-innovantes. Les informations sur ce type d'entreprises sont donc difficilement accessibles. De ce fait, notre analyse s'appuie sur les résultats d'une enquête réalisée auprès de 120 start-ups françaises (éco-innovantes et non éco-innovantes) que nous avons menée en 2019.

Nous contribuons à la littérature en apportant des clarifications sur différents points. D'abord, nous analysons la spécificité des entreprises éco-innovantes en considérant le thème du capital humain, ce qui nous permet de mettre en évidence l'importance des caractéristiques entrepreneuriales et notamment les connaissances accumulées par l'entrepreneur. Ensuite, nous établissons une typologie

des start-ups éco-innovantes en cinq catégories. Nous identifions les principaux déterminants ainsi que le type d'éco-innovation (incrémentale, radicale, frontstage...) développé par chaque catégorie de start-ups. Nous complétons notre approche en prenant en compte les capacités entrepreneuriales des start-ups (Casson, 2005). A notre connaissance, cette étude est la première analyse empirique consacrée aux déterminants de l'éco-innovation dans le cas des start-ups. Enfin, notre étude se démarque par l'originalité des données et la diversité des variables considérées issues d'une enquête que nous avons menée auprès des entreprises françaises, en 2019.

Chapitre 3 : Localisation des entreprises éco-innovantes : quel rôle pour les diffusions de connaissances ?

Malgré l'intérêt de plus en plus élevé accordé à l'étude des déterminants de l'éco-innovation, les facteurs spatiaux de création d'entreprises éco-innovantes ont reçu très peu d'attention dans la littérature. L'objectif de ce chapitre est d'analyser les déterminants spatiaux de l'entrée des entreprises éco-innovantes. Pour ce faire, nous essayons principalement d'apporter des réponses à trois questions :

- Quel est le lien entre l'accumulation des connaissances au niveau régional et la création d'entreprises éco-innovantes ?
- Dans quelle mesure la recombinaison d'innovations⁷ peut-elle impacter la création d'entreprises éco-innovantes ?
- La création d'entreprises dans un département peut-elle être influencée par la création d'entreprises éco-innovantes et la base technologique des départements voisins ?

Nous nous basons sur la théorie de l'entrepreneuriat par les diffusions de connaissances « knowledge spillover » (Acs et al., 2013, 2009), ainsi que la théorie évolutionniste de l'économie géographique et notamment la théorie de la recombinaison de connaissances (Boschma, 2017). Cette approche stipule que les nouvelles idées sont générées par la recombinaison des idées existantes. Nous considérons la configuration locale de la base de connaissances à travers deux indicateurs : parenté technologique et variété technologique⁸. L'indicateur « variété technologique » mesure le degré de diversification de la base technologique, alors que l'indicateur « parenté technologique » mesure le degré de complémentarité des technologies qui constituent la base de connaissances de chaque département.

⁷ La recombinaison d'innovation fait référence à la manière dont les anciennes idées peuvent être reconfigurées afin de générer de nouvelles idées (Castaldi et al., 2015; van den Bergh, 2008; Weitzman, 1998).

⁸ Traduction française des termes "knowledge variety" et "knowledge relatedness".

Dans cette étude, nous considérons les entreprises intensives en technologies environnementales qualifiées par Triguero et al. (2013) de leaders car elles investissent plus de 50% de leurs investissements d'innovation dans l'éco-innovation. Nous utilisons les données micro-économiques au niveau de l'entreprise pour définir l'entrée sur le département des entreprises éco-innovantes, mesurée par le dépôt du premier brevet environnemental. Ces données sont issues de la base de données de brevets REGPAT, associée à la base de donnée financière DIANE afin de prendre en compte les caractéristiques de l'entreprise, notamment sa date de création. Cette base de données a été complétée par les caractéristiques économiques et spatiales au niveau départemental issues de sources diverses telles que l'Insee et Eurostat. Nous avons élaboré une base de données d'entreprises éco-innovantes distribuées sur les 96 départements français pour la période 2003-2013. En utilisant un modèle linéaire généralisé (GLM), nous avons estimé l'entrée des entreprises éco-innovantes en fonction d'un ensemble d'indicateurs technologiques en contrôlant les caractéristiques locales. Pour tenir compte de la dépendance spatiale, nous avons estimé les entrées d'entreprises éco-innovantes en appliquant un modèle d'économétrie spatiale sur données de panel (Elhorst, 2014, 2010). Concrètement, un modèle spatial de Durbin (SDM) a été adopté.

Avec ce chapitre, nous contribuons à la littérature empirique de plusieurs façons. En premier lieu, nous calculons des indicateurs de connaissances technologique mesurés par les brevets : parenté technologique et variété technologique. Ces indicateurs permettent de comprendre la recombinaison des technologies qui constituent les innovations environnementales en France. En second lieu, nous introduisons des techniques d'autocorrélation spatiale afin de prendre en compte l'influence des régions voisines.

Au terme de cette recherche, nous aurons apporté différentes clarifications empiriques à l'analyse des facteurs qui influencent l'attitude des entreprises françaises face à l'éco-innovation, notamment en étudiant à la fois les déterminants de l'éco-innovation et l'incidence de l'éco-innovation sur l'activité des entreprises et également par la prise en compte de facteurs spatiaux et des caractéristiques entrepreneuriales individuelles.

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Chapitre 1

An assessment of the relationships between R&D, eco-innovation and productivity: Evidence from French firms⁹

1.1 Introduction

Due to climate change and the progressive degradation of the environment, green growth has become an important concern for many countries. Policy makers insist on the importance of making changes in the human mode of interaction with the environment as well as in the use of resources. In this respect, several national and international programs have now been devoted to sustainable development. In France, several laws and initiatives such as the road map for the circular economy (2018), the law on social and solidarity economy (2014) and the law on the energy transition for green growth (2015) have strengthened the organizations involved in the circular economy and the social economy. These sectors are considered to represent important potential for economic development as well as being an active field of recruitment. In fact, the green economy directly supported 4 million jobs (14% of total employment) in 2014, and production in eco-activities amounted to 85.7 billion euros (Commissariat général au développement durable, 2018).

In order to achieve the sustainable development objectives, more emphasis has been placed on innovation and in particular eco-innovation (Ekins, 2010). The government has expressed its desire to support eco-innovation: aid supplied by ADEME (Agence de l'Environnement et de la Maîtrise de l'Énergie) in the context of its program of investments for the future (PIA 2010–2017) for funding energy transition and eco-innovation projects is estimated at 2.5 billion euros (582 million devoted to small- and medium-sized firms) (ADEME, 2018). In 2014, R&D expenditure by the public and private sectors on issues relating to the environment was estimated to be around 5.1 billion euros, equivalent

⁹ This chapter has been presented in several conferences including AFSE, FAERE, ECFED and the 1st sustainability workshop.

to 11% of France's gross domestic expenditure on R&D. Of this expenditure, 51% was implemented by firms (compared with 20% in 2000) (Nisslé, 2017). France's eco-innovation performance is a little above the EU average and France is ranked 7th with an eco-innovation index¹⁰ of 112 (European Commission, 2018): it is classified among the European countries that are average eco-innovation performers. An important improvement can be seen compared to 2017, however, when it occupied the 13th rank. This shows the considerable efforts France has made to shift towards more environmentally friendly practices. In this context, from a policy perspective it is important to analyse the impact of government efforts on the stimulation of the investment in eco-innovation by firms.

In a market economy characterized by fierce competition and profit maximization, firms adopt technologies that are likely to generate higher benefits. However, due to environmental constraints such as limited natural resources, environmental regulation and an increasing demand for green products, firms must take into account the negative externalities of their technology strategies. Therefore, managing eco-innovation is becoming an increasingly important issue for firms.

As with all innovations, eco-innovation creates knowledge spillover. Given that technological learning is a public good, firms encounter difficulties in appropriating their innovations. A specific feature of eco-innovation is that, in addition to generating knowledge spillover, it also generates environmental spillover. When firms adopt or develop innovations that allow for the reduction of environmental impact, they bear the costs while all of society benefits from it. Therefore, environmental innovation allows firms to avoid negative externalities and to provide positive ones. Rennings (2000) has called this specific feature of eco-innovation "the double externality problem", and explains how this problem diminishes the incentives of firms to innovate.

The study of the impact of environmental regulation on firms' performance has attracted the attention of many researchers. For a long period, the negative effect on competitiveness has been the leading point of view for studies of environmental regulation. Indeed, when an additional constraint is imposed, firms face rising costs. Productive investments are thus discouraged due to the additional expenses incurred in reducing the negative externalities caused by pollution. This loss in competitiveness is followed by a decrease in exports. In the long run, we may expect the delocalization of firms (in particular those that are more polluting) to countries where environmental regulation is less restrictive. This is known as the 'pollution haven' hypothesis (Copeland and Taylor, 2004;

¹⁰ This measure indexes eco-innovation performance across the EU Member States. It aims at capturing the different aspects of eco-innovation by applying 16 indicators grouped into five dimensions: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes. https://ec.europa.eu/environment/ecoap/indicators/index_en

Letchumanan and Kodama, 2000). However, over the past two decades, several authors have criticized this point of view by developing a new approach known as the Porter hypothesis¹¹. It states that well-designed environmental regulation can stimulate innovation. It is precisely this innovation that will partially reduce or fully offset the compliance costs associated with the environmental regulation. A well-designed environmental policy leads to a win-win result: productivity gains and environmental protection (Porter, 1991; Porter and Van der Linde, 1995; Wagner, 2007).

This paper aims to study the drivers of eco-innovation and its effect on firms' performance using French firms data over the period 2006–2014. The contribution of this study is manifold. First, an extended CDM model that includes two types of R&D (environmental and non-environmental) is proposed in order to reveal any specificities of environmental innovation. Second, using data on patents, I consider different types of eco-innovation: renewable energy, waste management, and climate change mitigation technologies in production and transportation. Third, environmental regulation variables at the firm level are introduced as drivers of environmental innovation. Fourth, to our knowledge this is the first study to have explored this issue using recent data on French firms.

To meet these goals, patent data extracted from the REGPAT and HAN OECD databases are combined with financial firm data collected from the DIANE database and data on R&D drawn from the firm research expenditures survey. Data on environmental regulation and practices come from the community innovation survey (CIS). The analysis is based on an unbalanced panel sample of 7,136 French firms over the period 2006–2014.

The result show that there is an indirect positive contribution of environmental policy instruments in the form of taxes, fees or financial support on eco-innovation through their positive effect on environmental R&D. However, no significant effect is found for the productivity effect of eco-innovation. When differentiating between technology groups, only renewable energy reports a positive effect supported by the important role of subsidies. Despite the role of consumer demand

¹¹ Jaffe and Palmer (1997) distinguish 3 versions of the porter hypothesis:

-The “narrow” Porter hypothesis: is based on the idea that instruments design is important. It argues that flexible environmental instruments stimulate innovation and thus are better than the other types of environmental policy instruments.

-The “weak” Porter hypothesis : refers to the positive effect of environmental regulations on eco-innovation

-The “strong” porter hypothesis : suggest that environmental regulations prompt firms to create new innovations, the benefits generated by these innovations will allow to offset the costs of compliance. As a result, environmental regulations improve the economic performance of firms.

A number of studies have confirmed the link between environmental regulation and eco-innovation thus supporting the weak version of Porter's. However, there is little corroboration of the strong version of the hypothesis (see Lanoie et al., 2011).

for environmental products, the productivity effect of eco-innovation remains low. Thus, market incentives alone are not sufficient to enable a considerable increase in firms' environmental innovation. More efforts in terms of green promotion and environmental regulation will be important for such innovations to flourish.

The paper is organized as follows: Section 2 provides a literature review. Section 3 outlines the data. Section 4 introduces the model and the variables. Section 5 presents the results, while Section 6 concludes.

1.2 Literature review

Within the measuring eco-innovation report, eco-innovation is defined as “the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives” (Kemp and Pearson, 2007). According to this definition, an innovation does not need to be new to the market to be described as an eco-innovation; it is sufficient that it is new to the firm (development or adoption). This definition includes all innovations that are beneficial to the environment regardless of the motivation behind their development or adoption (in other words an environmental objective is not defined a priori); the field of eco-innovation is extended to include innovations that contribute unintentionally to protecting the environment (bikes and insulation materials, for example). Yet when considering this broad definition of eco-innovation, it is hard to find an indicator that is suitable for measuring it. As with classical innovations, patents and research and development are among the most widely used indicators for measuring eco-innovation. Research and development (R&D) is an indicator of the input of innovation, generally reflecting technological eco-innovation and formal R&D. Patents are essentially a measure of the output of eco-innovation, and have several advantages, including the availability of disaggregated data from several countries over several years and the possibility of dividing them into several categories (using IPC or CPC classification). Although they provide detailed information on innovations, however, the use of patents can be contested. Some innovations are indeed not patentable, while other means such as secrecy can be used by firms to protect their innovations. Large firms are more likely to use patents than small firms. Generally, only technological eco-innovation is patented, so patents cannot measure organizational and social eco-innovation. Patents generally reflect intentional eco-innovations (those whose main objective is to reduce the environmental impact). Moreover, most often they reflect innovations that are new to the market but not innovations that are

new to the firm. The use of this indicator therefore restricts the definition of eco-innovation; yet despite these shortcomings, patents are a widely used indicator in the literature as a measure of eco-innovation (among others, see Brunnermeier and Cohen, 2003; Jaffe and Palmer, 1997; Marin, 2014; Marin and Lotti, 2017; Soltmann et al., 2013).

The eco-innovation effects of environmental regulation (the weak version of the Porter hypothesis) have attracted increased attention among economists, these studies in general revealing a significantly positive effect of environmental regulation on eco-innovation (R&D or patents). The measurement of environmental regulations is a crucial issue in this line of research. The “Pollution Abatement and Control Expenditures” (PACE) measure is used as the proxy variable in many existing studies (among others, see Berman and Bui, 2001; Brunnermeier and Cohen, 2003; Jaffe and Palmer, 1997).

In studying the effect of PACE on innovation (R&D and patents (without differentiating environmental and non environmental patents)) in US firms, Jaffe and Palmer (1997) found that PACE has a positive impact on R&D, but that the effect on patents is not significant. In the same case, Brunnermeier and Cohen (2003) found that PACE has a positive but low effect on eco-patents. The same positive sign can also be found in Kneller and Manderson (2012) for the case of the UK industries. They provided some further insights by showing a crowding out effect of environmental R&D on non-environmental R&D. Investments that may be dedicated to non-environmental innovation are reallocated to environmental innovation.

Some authors have focused on the stringency of environmental regulations and the impact of different types of instruments (the narrow version of the Porter hypothesis). In this sense, market-based and flexible instruments such as emissions taxes, tradable allowances or performance standards, are more favorable to innovation than command-and-control instruments such as technological standards (Lanoie et al., 2011; Xie et al., 2017). By focusing on the case of renewable energy at country level, Johnstone et al. (2009) showed that environmental policy instruments play a key role in stimulating environmental innovation. However, the impact of different types of instruments varies depending on the type of renewable energy: renewable bonds only have an effect on wind patents, and feed-in tariffs have a positive impact on solar patents.

A range of empirical studies have been devoted to testing the effect of environmental innovation on firm performance, without, however, looking at the cause of this variation in performance (whether it is linked to innovation or to another cause).

Different measures of firm performance are used, including Tobins' q index (Dowell et al., 2000; Lee and Min, 2015), returns on sales (Ghisetti and Rennings, 2014), and productivity (Soltmann et al., 2013). Those studies provided a very mixed picture on the signs of this relationship.

Some papers highlight a negative impact of environmental regulation on productivity. For instance, Soltmann et al. (2013) show that the stock of environmental patents is negatively correlated with productivity. The relationship between environmental innovations and productivity is U-shaped. Innovations are beginning to have a positive effect on performance from a number of 3014 patents. Focusing on the case of European firms, Kruse (2016) finds a negative effect of green energy innovations on firms' performance. This negative effect is more pronounced for larger firms. Other authors find more positive results. Colombelli et al. (2015) show that eco-innovation triggers firm growth; firms that adopt eco-innovation have higher growth rates of sales than firms adopting classical innovation. Similarly, Lee and Min (2015) find evidence that eco-innovation has a positive effect on Japanese manufacturing firms' financial performance.

Some authors raise the question that it is no longer whether it does pay to be green, but rather how it pays to be green (Ghisetti and Rennings, 2014). Ghisetti and Rennings (2014) studied this question for the case of German firms: they point out that energy efficiency innovations positively impact firms' performance, while innovations allowing the reduction of negative externalities (such as air, water, noise and soil pollution) have a negative impact on firms' performance.

A relatively large number of studies have been conducted on another line of research that directly relates environmental regulation to productivity (the strong Porter hypothesis). Overall the results are also mixed, and there is no universal consensus on this issue (see Albrizio et al. (2014), for a recent review). For example, using detailed production data from nearly 1.2 million US plant observations, Greenstone et al. (2012) found that total factor productivity declines by 4.8 percent for polluting plants in strictly regulated counties compared to weakly or unregulated counties. This corresponds to an annual economic cost from the regulation of manufacturing plants of roughly \$21 billion (in 2010 dollars), or 8.8 percent of average manufacturing sector profits over the period of analysis. Wang et al. (2019) analysed this relationship at country level using an environmental policy stringency index that allowed them to take into account different types of environmental instruments and to include different levels of environmental regulation stringency at the country level. They report that environmental regulation is positively correlated with green productivity growth. However, when the stringency of environmental regulation policy rises over a certain extent, it changes to an adverse effect on green growth, revealing an inverted U-shaped relationship.

However, several articles in the literature have used reduced form models (single equation models) by testing one part of the relationship that links environmental regulation to productivity, and

most of them focused on macro- and meso-economic data (country- and industry-level approaches). There is still a relative scarcity of articles aimed at investigating the whole chain of the relationship by studying the indirect effect of environmental regulation on productivity through eco-innovation at firm level (the strong Porter hypothesis). Among the authors who have used complete form models we can mention Lanoie et al. (2011), Doran and Ryan (2012), Marin (2014), Marin and Lotti (2017), Van Leeuwen and Mohnen (2017) and Dussaux (2015). Lanoie et al. (2010) combine the different approaches by assessing, for the first time, the whole causality chain that links environmental regulatory stringency to eco-innovation and firm performance. They argue that environmental regulation induces eco-innovation. This latter has a positive effect on firm performance. This provides evidence for the strong form of the Porter Hypothesis, that environmental regulation spurs eco-innovation which further enhances firm performance. However, environmental regulation has a direct negative effect on business performance. They conclude that the positive effect of innovation on firm performance does not outweigh the negative effect of the environmental regulation. Focusing on the case of Irish firms, Doran and Ryan (2012) find that existing and expected regulations and government incentives in the form of grants positively impact the firm's inclination to engage in eco-innovation. Firms that introduce eco-innovation have higher levels of turnover per employee than firms that innovate in classical innovations and firms that do not engage in innovation activity. Some authors have used administrative data (balance sheet and income statements) which gives more objective and standardized information (Marin, 2014). The main findings, for the case of Italian firms, suggest a crowding-out effect of green innovations on non-green innovations in the short run, where the crowding-out effect is more pronounced for polluting firms. Moreover, Marin (2014) shows that environmental innovations have no significant effect on firms' performance, while non-environmental innovations have a positive effect. Marin and Lotti (2017) carried out a similar analysis using patent data and survey data, as we also do in our case. They conclude that both environmental and non-environmental innovations have a positive effect on firm performance. However, environmental innovations display a lower return compared to non-environmental innovations. Furthermore, their results also confirm the crowding-out of environmental innovation relative to non-environmental innovation. Focusing on the case of Netherlands, Van Leeuwen and Mohnen (2017) find that there is a significant positive contribution of environmental regulation and environmental levies (total environmental exploitation costs) on eco-innovations. Moreover, he finds that resource-saving eco-innovations increase productivity, whereas pollution-reducing eco-innovations tend to reduce productivity. Therefore, eco-innovation globally does not turn out to be significant. Environmental regulations, if properly aimed at process-integrated eco-innovations, can have a positive effect on TFP. Dussaux (2015) raises this question for the case of French firms, arguing that environmental regulations lead to the development of more green innovation, but that environmental innovation

doesn't lead to productivity gains. He finds robust evidence that higher environmental effort leads to a change in the direction of innovation towards cleaner technologies but has no effect on the scale of innovation.

The studies described above differ considerably in their method, geographical scope and the indicators used as proxies for the variables. The results are mixed and the relationship remains ambiguous. In line with the empirical literature I analyze the effect of environmental innovation on firm performance using data on French firms. I adopt a different approach to Dussaux (2015), however, by using an extended CDM model to test the indirect effect of environmental regulation on productivity. As suggested by Dussaux (2015), patent data—namely, indicators of actual innovation which provide information about specific technologies—are used in this article, so as to deal with the possible bias due to the fact that the data from the CIS are the firm's "perceived" effects of their innovation. Contrary to Van Leeuwen and Mohnen (2017) who used a model similar to mine, I use patent data as proxy for environmental innovation, which allows me to consider different types of environmental innovation (waste management, climate change mitigation technologies in transportation and production and renewable energy technologies). I also consider non-environmental research and development as a factor that plays an important role to spur eco-innovation under the assumption of complementarity between non-environmental innovation and environmental innovation. Voluntary initiatives of firms (such as certification) towards the protection of the environment, and market demand of consumers for environmental products and processes, are also considered. In contrast to Marin (2014), I consider environmental regulation and market forces at firm level, and this study is based on a more accurate measure of R&D achieved by also considering the environmental R&D. In addition to the two latest stages of the CDM model considered by Doran and Ryan (2012), I also consider the first-stage testing for the drivers of the decision to perform R&D and its intensity.

1.3 Data

1.3.1 Presentation of data

The sample was constructed by merging 4 firm-level databases: REGPAT, DIANE, CIS survey and R&D survey.

(a) Patent data comes from the REGPAT database released by the Organisation for Economic Cooperation and Development (OECD), which is derived from the Worldwide Patent Statistical Database "PATSTAT" maintained by the European Patent Office (EPO). Careful consideration must

be given to the extraction of data. Indeed, some characteristics of patents may induce multiple counting when associating patents to a country, technology or company; for example, several patents may be the result of a collaboration between more than one inventor or applicant. Similarly, patents can be protected in more than one country. Many alternatives are available for patent counts according to the question we want to answer.

In this article, simple patents count is used as a proxy for innovation; a dummy variable is built from this proxy. The patent count is conducted using specific selection criteria. Only the patents filed in the EPO¹² by companies located in France are considered. Applicant count rather than inventor count is chosen because environmental innovation is specific for each country and depends on the country where the firm is located. Inventor's country reflects the country of origin of inventions while the applicant country reflects the ownership of inventions and gives an idea concerning the innovative performance of firms in a given country. The application priority year¹³ is used as year of reference, since it is reasonable to suppose that this is the closest date to the date of invention. Firms that filed at least one patent in the study period are considered. Data was extracted for both non-environmental innovations and environmental innovations.

In REGPAT, patents are assigned to technological fields using two types of classification: the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC). Until now, most studies have been based on the IPC code (Kruse, 2016; Marin, 2014). When using this method one should look for green patents in different classes: several authors have explained how to combine these codes to select the patents belonging to a specific technological field (Dechezlepretre et al., 2011; Johnstone et al., 2009). This data retrieval method carries two risks: selecting irrelevant patent applications and excluding relevant patent applications (Veefkind et al., 2012). Since 2013, the EPO has completed the CPC classification which includes a classification dedicated to applications related to green technologies (see table 1). A search strategy based on CPC is an easier and more reliable way to select green patents (for more details, see Veefkind et al., 2012). In our study, patents are attributed to technological fields according to CPC codes. I consider the main CPC codes and all their subclasses. It is worth mentioning that a patent can be attributed to more than one CPC code and some patents don't have a CPC code.

¹² This is a regional office including 38 European members in 2017. Applicants submit a patent application to this office when they want to protect their inventions in several European countries. This procedure is used when the applications are expected to be of high value and commercially profitable.

¹³ Several dates are attributed to a patent. The priority year is the year of the application priority date. This refers to the date when an application is filed for the first time anywhere in the world to protect an invention.

(b) Financial data is drawn from the DIANE database maintained by the Bureau Van Dijk (BVD).¹⁴ This database contains information about balance sheet of approximately 16 million French firms. The first available year in DIANE is 2003. The study is based on the unconsolidated financial statements.

(c) R&D data comes from the annual firm research expenditures survey conducted by the French Ministry of Higher Education, Research and Innovation. All companies employing at least one full-time equivalent researcher are included in the survey. The R&D survey is designed so that very large companies participate in the survey for the entire period. However, medium and small businesses are selected by sampling. All companies likely to have an R&D activity selected through the information provided by the various administrative procedures (such as the National Agency for the Valorization of Research (AVNAR)) are investigated at least once. The expenses used here are intramural R&D expenses.¹⁵ The target for this survey is the availability of the share of R&D devoted to the environment.

(d) Environmental regulation variables come from the French Community Innovation Survey (CIS), conducted every two years since 1994. The aim of the CIS survey is to provide a comprehensive survey of the innovation performance of French firms. The survey is conducted as part of the European wide community innovation survey project.

1.3.2 Data matching procedure and descriptive statistics

The construction of the sample was quite laborious. First, the full version of DIANE was merged with a smaller version of the REGPAT database that contains all the firms that filed at least one patent over the study period. Due to the absence of a common identifier between the REGPAT database and the other databases, the name and the address of companies were used to merge these two datasets. Company names and addresses are not uniform and there are spelling differences. In this case, harmonization of names and addresses was necessary. The OECD's Harmonization of Applicant Names (HAN) dataset is used to address some of these difficulties. After that, the two datasets were matched using an algorithm. The result of the firm matching was checked manually, on a case-by-case basis.

¹⁴ I used the 2017 version.

¹⁵ Intramural R&D is defined by Doran and Ryan (2013) as creative work undertaken within the enterprise to increase the stock of knowledge for developing new and improved products and processes.

Then the resulting sample was added to the R&D database. I considered all companies that responded to the R&D survey at least once during the data availability period (2003–2015). Companies that do not have R&D activity were selected by considering companies that do not appear in the R&D database during the entire data availability period (2003–2015). These null values were checked using the CIS survey data, which includes a question on whether the company is engaged in research and development activities. Some companies that participated in the R&D survey and were not recorded in the DIANE database were not taken into account because of the unavailability of certain financial data.

R&D activities in groups of firms are very dependent on their general organization. In some cases groups set up a research center that carries out all the research activity of other companies of the group in France or in the world. In addition, some companies provide answers that include the research activities of several subsidiaries of the group. Those firms are deleted from the dataset. After doing so, the resulting sample was completed by information on environmental regulations from the CIS database. However, information on environmental regulation is only available for two waves (2008 and 2014). To include as many observations as possible, I set the values for the years 2006 and 2007 equal to those of 2008 and the years 2012 and 2013 equal to those of 2014. I do so for all the variables taken from CIS survey (essentially environmental regulation variables), which is not unreasonable since the CIS surveys of 2008 and 2014 cover respectively the periods 2006–2008 and 2011–2014. This operation has the effect of considerably reducing the size of the sample. Finally, the data was cleaned up by removing implausible values such as recorded negative added values. The last estimation step (productivity equation) contains fewer observations due to missing values of value added.

The selected sample is an unbalanced panel that contains observations for 2,877 firms over the period 2006–2014. Table 1.1 and table 1.2 report some descriptive statistics and the distribution of the observations for the unbalanced sample. It is worth noting that the sample is essentially made up of large¹⁶ firms (97.11%); 25.51% of the firms are involved with environmental R&D but only 6.88% of firms have filed at least one patent and even fewer have filed an environmental patent (2.81%). Another interesting point concerns the fact that the majority of firms that have filed an environmental patent have also undertaken environmental R&D activity. Almost 50% of the firms are subject to environmental regulation and 4.86% of these firms are especially involved with the European Union Trading Scheme.

¹⁶ I here adopt the DIANE database classification of firms into large, small and medium.

Table 1.1 Descriptive statistics

Variable	Description	Source	Obs	Mean	Std. Dev.	Min	Max
I_RD	Total internal R&D per employee	R&D survey	7136	14.78575	26.83233	0	590.4889
I_ENVRD	Environmental R&D per employee	R&D survey	7136	0.7086559	4.300837	0	132.2
I_RDNE	Non-environmental R&D per employee	R&D survey	7136	14.07709	26.30955	0	590.4889
MARKET_SHARE	Market share (%)	Own elaboration from DIANE	7136	2.659953	7.839286	0	97.62301
L	Number of employees	DIANE	7136	1019.441	6676.183	1	236185
K/L	Physical capital (tangible capital asset) per employee	DIANE	7136	59.79915	383.2044	0.0049235	14864.38
VA/L	Value added per employee	DIANE	4902	97.50646	374.1164	0.2050526	23872.99
REGULATION	Environmental regulation	CIS survey	7136	0.4831839	0.4997522	0	1
SUBVENTION	Environmental subvention	CIS survey	7136	0.2900785	0.4538302	0	1
ENV_DEM	Market demand for environmental products	CIS survey	7136	0.4126962	0.4923535	0	1
ENV_INITIATIVE	Voluntary environmental practices	CIS survey	7131	0.5585472	0.4965952	0	1
D_AGE	Age of the firm (dummy)	DIANE	7136	0.478139	0.4995569	0	1
D_ENVP	Environmental patents	REGPAT	5694	0.028451	0.1662721	0	1
D_RENW	Renewable energy patents	REGPAT	5694	0.0059712	0.0770492	0	1
D_WM	Waste management patent	REGPAT	5694	0.0017562	0.0418743	0	1
D_CCMT	Climate change mitigation patents	REGPAT	5694	0.0210748	0.1436464	0	1

Table 1.2 Distribution of the observations for the main variables of the study

Period (2006-2014)	%	Period (2006-2014)	%
Firms that filed at least one patent Over the period of study	7,16	Firms that filed at least one environmental patent subject to environmental regulation	2,18
Firms with environmental R&D	25,51	Large firms	97,11
Firms that filed at least one non-environmental patent	6,88	Small and medium firms	2,88
Firms that filed at least one environmental patent	2,81	Firms with environmental R&D and subject to environmental regulation	17,37
Firms subject to environmental regulation	46,40	Firms subject to the European union emission trading scheme (EU ETS)	4,86

1.4 Empirical methodology

The econometric analysis is based on a modified version of the CDM model proposed by Crépon et al. (1998) to explain the relation between innovation and productivity by linking the input of innovation (R&D) to the output of innovation (in the present study, patents) and innovation to productivity. The advantage of the structure of the model is that it allows us to handle two problems inherent in innovation data: selection bias and endogeneity. The selection bias problem is due to the truncation of innovation data. Input innovation data (research and development, cooperation, etc.) is only reported by firms that have actually carried out innovation activities. So it is necessary to correct for data truncation. Moreover, the decision to undertake R&D activity is simultaneously determined by other factors, which may in turn be affected by R&D. The CDM model is a sort of instrumental variable approach intended to correct these two flaws. This approach comprises three stages formalized by three simultaneous equations: R&D decision and intensity, the innovation equation, and the productivity equation.

1.4.1 R&D decision and intensity of investment

The purpose of this first stage is to model the decision of firms concerning whether to undertake R&D investment, and then to determine the intensity of this investment. I test different specifications of the model by considering the total R&D, the environmental R&D and the non-environmental R&D. The equations for each type of input have the form of a generalized Tobit type II model. The two-step Heckman method (Heckman, 1979, 1976) is adopted to estimate the model; it consists of estimating the decision equation by a dichotomous Probit, and then constructing the Mills ratio from the first stage estimator and introducing it into the regression of the R&D intensity. It is specified as follows:

$$D_RD_{it} = \begin{cases} 1 & \text{si } RD_{it}^* = x_{it} \beta + \varepsilon_{it} > \bar{c} \\ 0 & \text{si } RD_{it}^* = x_{it} \beta + \varepsilon_{it} \leq \bar{c} \end{cases} \quad (1)$$

Where i indexes the firm, t indexes the year. D_RD_{it} is a dummy variable that takes the value 1 if the firm i reports a positive R&D, RD_{it}^* is a latent indicator variable such that a firm decides to undertake R&D investment if this indicator is above a given threshold \bar{c} which represents an unobservable expected returns on R&D, and x_{it} represent the explanatory variables. I employ the following variables: the firm's market share (MARKET_SHARE), defined as the ratio between the firm's total sales and the total sales of all the firms belonging to the same sector (this variable is built from a three-digit NACE classification). The Labor (L), defined as the number of employees in logarithm, where larger firms are expected to have greater means and incentives to invest in eco-innovation. The

physical fixed capital (K), defined as the intangible fixed assets (expressed per employee and in logarithm). Government can internalize the environmental externalities by imposing environmental regulations; therefore, existing or anticipated environmental regulation¹⁷ (REGULATION) is considered. The importance of market forces is also tested by including the variable current or expected market demand from customers for environmental innovations (ENV_DEM). Year dummies control for changes in the propensity to patent through time. Sector dummies control for sector-specific propensities to apply for a patent. ε_{it} is an error term.

The intensity equation is given by:

$$I_{RD_{it}} = \begin{cases} I_{RD_{it}}^* = x_{it} \beta + \varepsilon_{it} & \text{si } D_{RD_{it}} = 1 \\ 0 & \text{si } D_{RD_{it}} = 0 \end{cases} \quad (2)$$

$I_{RD_{it}}^*$ is the unobserved latent variable representing the firm's R&D intensity. The explanatory variables x_{it} are the same as that in equation (1). A dummy variable Age is added, which takes the value 1 if the firm is older than 10 years. It is worth noting that subsidies or other financial incentives for environmental innovation are a key variable for this step, assuming that a firm's age and subsidies affect the intensity of R&D and not the probability of performing R&D. The predicted values of R&D ($I_{RD_{it}}^*$) are introduced in the second equation presented below.

1.4.2 The innovation equation

As a second stage, the relationship between the input of innovation and the output of innovation is analyzed. Environmental patents (ENVP) are used as a proxy for eco-innovation. Due to the fact that less than 1% of the firms have filed more than 1 environmental patent, the dependent variable is a

¹⁷ We were unable to separate public policy instruments into command and control instruments and economic instruments due to the structure of the 2008 CIS survey questionnaire. The variable is constructed from the question below which combines these two instruments in the same answer. Therefore, the variable that we have named regulation combines the two instruments.

During 2006 to 2008, did your enterprise introduce an environmental innovation in response to:

- Existing environmental regulations or taxes on pollution.
- Environmental regulations or taxes that you expected to be introduced in the future
- Availability of government grants, subsidies or other financial incentives for environmental innovation
- Current or expected market demand from your customers for environmental innovation

binary variable equal to 1 if the firm has filed at least one environmental patent and 0 otherwise. Three types of environmental patents are considered: renewable energy (D_RENW), waste management (D_WM), and climate change management technologies in transportation, production and building (D_CCMT). When two (or more) correlated binary response variables are regressed on explanatory variables, two (or more) logistic regressions could be performed, but this is inefficient since the relationship between the two (or more) binary response variables is not utilized (Lesaffre and Molenberghs, 1991). The multivariate probit model fully exploits the correlation structure and thus offers a valuable solution to the problem. Even with a binary dependent variable, where the application of a classical logistic or probit regression seems natural, the bivariate (or multivariate) probit model may sometimes be preferable (Poirier, 1980). Because of the possible correlation between the different types of eco-innovation, a multivariate probit model is used for the estimation of the patent equation.

The equation is specified as follows:

$$ENVP_{it} = \alpha I_{RD}_{it}^* + \gamma w_{it} + \varepsilon_{it} \quad (3)$$

I_{RD}^* is the predicted R&D obtained from the first stage. w_{it} represents a vector of explanatory variables. I use the same classification of the drivers of eco-innovation as Horbach (2008). In this respect, I distinguish 3 sets of factors: technology push, demand pull, and regulatory push. Technology push drivers of eco-innovation mainly relate in this study to “internal technological” capabilities by means of the predicted R&D intensity from the first step. Innovation input is expected to have a positive effect on patents (Horbach, 2008; Mansfield, 1986). Demand pull drivers relate to current or anticipated demand from consumers for environmental innovations (ENV_DEM) and the environmental awareness of firms by setting up procedures to regularly identify and reduce their environmental impacts (ENV_INITIATIVE) (for example, preparing environmental audits, setting environmental performance targets, obtaining ISO 14001 certification, etc.). The role of Environmental Management Systems (EMS) such as the ISO14001 standard in promoting innovation has been investigated in several studies (among others, see Rennings et al., 2006; Wagner, 2007). Regulatory push drivers relate to the existence of government subsidies or other financial incentives for environmental innovations and existing or anticipated environmental regulation. The size of the firm (number of employees) and time dummies are also included.¹⁸

¹⁸ Because of multicollinearity problems, sector dummies are not considered in this stage.

1.4.3 The productivity equation

The last stage is devoted to estimating the indirect impact of environmental regulation on productivity via the effects of eco-innovation. A Cobb-Douglas production function is used. The equation is extended by adding the innovation variable ($ENVP_{it}^*$) predicted in the second stage.

$$\ln VA_{it} = \ln A + \alpha \ln L_{it} + \beta \ln K_{it} + \gamma \ln ENVP_{it-1}^* + \varepsilon_{it} \quad (4)$$

Where VA_{it} is the labor productivity (value added per employee and in logarithm). K_{it} is the capital (fixed physical assets per employee and in logarithm). Since the innovation output measures are endogenous, I instrument them by the predicted latent eco-innovation variable from the second stage (see e.g. Wooldridge, 2002).¹⁹ $ENVP_{it-1}^*$ is a lagged one-period variable.²⁰ I consider that there is a time delay between innovation and its impact on productivity. I also include the log of employees, the coefficient of which captures deviations from constant returns to scale,²¹ and I control for industry and year dummies. This final equation is estimated with a fixed effect model. Two specifications are tested for: on the one hand, I consider all the environmental patents; on the other, I distinguish between different categories of environmental innovation predicted from the second stage (renewable energy, waste management and climate change mitigation technologies).

To sum up, the model is made up of equations (1), (2), (3), (4) which are estimated sequentially. Following Griffith et al. (2010), the estimates are made for all firms, not just those that innovate.

¹⁹ As a robustness check I also account for the endogeneity of the traditional inputs by instrumenting them by their lagged values.

²⁰ Other lags are tested for but are not considered because of a drop in the number of observations.

²¹ A general Cobb-Douglas production function with two inputs (labour, L, and capital, K) is given by the equation $VA = AK^\alpha L^\beta$. Constant returns to scale imply that $\alpha + \beta = 1$. Dividing both sides by L, taking the log and rearranging we obtain $\log\left(\frac{VA}{L}\right) = \log(A) + \alpha \log\left(\frac{K}{L}\right) + (\beta + \alpha - 1)\log(L)$. Under the assumption of constant returns to scale, the parameter for $\log(L)$ should be zero ($\beta + \alpha = 1$). The same concept applies with more than two inputs (Marin, 2014).

1.5 Results

Table 1.3 reports the results of equations (1) and (2) (the R&D selection and intensity equations) at the first stage. Three specifications are tested: columns (a), (b) and (c) present respectively the results for total R&D, non-environmental R&D and environmental R&D²².

In the intensity equations, we observe that the inverse Mills ratios are significant, showing the importance of taking the selection problem into consideration. Firm size measured by number of employees has a positive impact on the decision to undertake R&D (for all the specifications). Thus the larger the firm, the more likely it is to engage in R&D activities. Bigger firms are more likely to be willing to incur the initial sunk costs of R&D activities, they have easier access to credit, and they are more capable of bearing the risk related to R&D investments whose returns are highly uncertain Marin (2014). In line with the results provided by Hall et al. (2013) and Marin and Lotti (2017), conditional on investing, R&D intensity decreases with size.

Fixed physical capital doesn't affect the decision to invest in R&D except the case of environmental R&D. By contrast, it has a positive and significant effect on the intensity of environmental and non-environmental R&D. This indicates that in case a firm chooses to invest in R&D, a complementarity between R&D and total assets seems to arise.

Market share is negatively related to the probability of performing R&D (except for environmental R&D where the effect is insignificant) whereas it positively affects its intensity. This result is in line with Marin (2014), who argues that firms holding a dominant market position have little incentive to innovate and prefer to defend their dominant position rather than explore new markets or change their production technology. On the other hand, however, once they decide to innovate, there is strong incentive to exploit the current large customer base. The variable Age is significantly negative in intensity equations of total and environmental R&D, meaning that older firms have a lower probability of performing R&D (except for the case of environmental R&D, which shows a non-significant effect).

Environmental R&D reacts more strongly to environmental subsidies and environmental regulation. In fact, current or anticipated environmental regulation has a strong positive effect on the probability of performing environmental R&D, and the existence of government subsidies or other financial incentives for environmental innovations has a strong positive effect on the environmental R&D intensity (these two variables don't have a significant effect on non-environmental R&D). Current or anticipated demand from consumers for environmental innovations has also a strong

²² A robustness check was performed by using the large firms only; results are robust and available upon request.

positive effect on the decision to undertake environmental R&D. This variable has also a positive effect on total R&D. I conclude from this stage that environmental policy instruments in the form of taxes, charges, fees or subsidies have a positive effect on the environmental R&D investment.

This third stage looks at the productivity impact of different types of eco-innovations. The results are shown in table 1.5. Firms are characterized by strong increasing returns to scale (the log of employee count is significantly greater than zero and its magnitude is quite relevant). I test different specifications of the variable predicted environmental patents by considering: total environmental patents (column (a)), different types of environmental patents estimated in one productivity equation (column (b)), and different types of environmental patents estimated separately (columns (c), (d), (e)).

The coefficients on employment and total assets are both positive and statistically significant. This result is in line with general expectations.²³ No significant effect is found for the total predicted environmental patents (column (a)).

The productivity effect of renewable energy patents is positive and significant. The positive return of this kind of eco-patent, when compared to the null effect of environmental patents as a whole, may be driven by the key role of subsidies and other government financial grants (such as feed-in tariffs), as found in the results of the second step.

Climate change mitigation technologies show a negative effect in column (b). The waste management predicted patents are not significant for all specifications.

²³ As a robustness check I also let the traditional factors of production be endogenous and instrument them by their one-period lagged values; the result did not change significantly.

Table 1.3 Eco-innovation input equations

VARIABLES	(a) Total R&D		(b) Non-environmental R&D		(c) Environmental R&D	
	I_RD	D_RD	I_RDNE	D_RDNE	I_RDENV	D_RDENV
MARKET_SHARE	0.0147*** (0.00465)	-0.0113*** (0.00414)	0.0125** (0.00618)	-0.0107*** (0.00390)	0.00987** (0.00483)	0.00174 (0.00282)
Ln (L)	-0.119*** (0.0319)	0.181*** (0.0217)	-0.0658 (0.0533)	0.200*** (0.0197)	-0.104 (0.0788)	0.0865*** (0.0145)
Ln (K/L)	0.148*** (0.0238)	-0.0174 (0.0205)	0.144*** (0.0308)	-0.0150 (0.0187)	0.127*** (0.0372)	0.0294* (0.0154)
REGULATION	0.130 (0.0827)	0.134* (0.0800)	0.0940 (0.105)	0.0195 (0.0701)	0.372 (0.270)	0.292*** (0.0470)
SUBVENTION	0.0981 (0.0831)		0.0495 (0.105)		0.177*** (0.0605)	
ENV_DEM	0.0964 (0.0851)	0.264*** (0.0821)	0.0395 (0.104)	0.0781 (0.0701)	0.503 (0.356)	0.400*** (0.0449)
D_AGE	-0.123** (0.0576)		-0.127* (0.0731)		-0.0480 (0.0479)	
Constant	0.817*** (0.287)	0.732*** (0.183)	0.538 (0.426)	0.724*** (0.172)	-2.867 (2.823)	-2.159*** (0.131)
Lambda	2.342*** (0.791)		3.012*** (1.143)		1.627 (1.184)	
Observations	7,136	7,136	7,136	7,136	7,136	7,136

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 1.4 Eco-innovation output

VARIABLES	Probit		Multivariate Probit	
	(1)	(2)	(3)	(4)
	D_ENVP	D_RENW	D_WM	D_CCMT
Ln (I_RD*)	0.531*** (0.126)	0.291*** (0.0756)	0.0387 (0.115)	0.253*** (0.0459)
Ln (L)	0.636*** (0.0895)	0.304*** (0.0464)	0.346*** (0.111)	0.348*** (0.0335)
ENV_DEM	0.581*** (0.210)	0.253* (0.145)	0.513** (0.221)	0.345*** (0.109)
REGULATION	-0.185 (0.220)	0.00583 (0.139)	-0.271 (0.222)	-0.0940 (0.122)
ENV_INITIATIVE	0.528** (0.234)	-0.118 (0.143)	0.141 (0.302)	0.304** (0.125)
SUBVENTION	0.0850 (0.192)	0.337* (0.190)	0.0127 (0.207)	0.198 (0.129)
Constant	-9.147*** (0.920)	-5.305*** (0.445)	-5.807*** (0.739)	-4.828*** (0.252)
atrho21		0.557*** (0.163)		
atrho31		0.457*** (0.0719)		
atrho32		0.275*** (0.0866)		
Observations		5,690		
Number of firms		2,644		

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 1.5 Labor productivity

VARIABLES	(a) Ln (VA/L)	(b) Ln (VA/L)	(c) Ln (VA/L)	(d) Ln (VA/L)	(e) Ln (VA/L)
L. ENVP*	0.0262 (0.0217)				
L. RENW*		0.0981*** (0.0368)	0.0783** (0.0305)		
L. WM*		0.0353 (0.0304)		0.0410 (0.0262)	
L. CCMT*		-0.0708* (0.0402)			0.00475 (0.0320)
Ln(L)	0.0348** (0.0168)	0.0387** (0.0160)	0.0308** (0.0130)	0.0365*** (0.0138)	0.0490*** (0.0154)
Ln(K/L)	0.0747*** (0.00975)	0.0766*** (0.00972)	0.0743*** (0.00960)	0.0757*** (0.00959)	0.0769*** (0.00974)
Constant	4.007*** (0.180)	4.108*** (0.183)	4.146*** (0.147)	4.022*** (0.153)	3.824*** (0.154)
Observations	2,607	2,607	2,607	2,607	2,607
Number of firms	1,447	1,447	1,447	1,447	1,447

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

1.6 Conclusion

In this paper, I investigate the drivers of eco-innovation and its effect on productivity. Different types of R&D (total, non-environmental and environmental R&D) are tested, and I differentiate between three types of environmental patents (renewable energy, waste management, and climate change mitigation technologies in transportation, production, and transportation).

The study is based on an unbalanced panel of 2,877 French firms over the period 2006–2014. To constitute the panel, patent data drawn from REGPAT is matched with financial data extracted from the DIANE database, R&D data drawn from the firms' research and development (R&D) survey, and environmental policy instruments data extracted from the community innovation survey (CIS). I use a CDM model that allows us to control for the selection bias and endogeneity that characterizes innovation data.

The results show that there is an indirect positive contribution of existing or anticipated environmental regulation on eco-innovation through its positive effect on environmental R&D. No significant effect is found for this variable in the case of eco-innovation output (environmental patents). Climate change mitigation technologies in production, transportation and building are essentially driven by consumer market demand for environmental innovation and the voluntary initiatives of firms to regularly identify and reduce their environmental impacts.

Subsidies or other government financial incentives play a key role in stimulating investment in renewable energy technologies, another factor that contributes strongly to the flourishing of this kind of eco-innovation is the market demand for environmental innovation. A weak effect is observed for existing or anticipated regulation indirectly through environmental R&D but an insignificant effect is observed directly through their positive effect on environmental patents.

Looking at the productivity effect of all environmental patents, on the other hand, I find a non-significant effect. I also find evidence for different productivity effects across environmental technologies. A positive effect on productivity is only observed for firms engaging in renewable energy, while a negative effect is observed for climate change mitigation technologies in the short run (one-year lagged variables). The positive effect of renewable energy is supported by government subsidies and other financial incentives and consumer market demand for environmental innovation.

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Appendix 1.1 : CPC classification of environmental technologies/

Technology	CPC code
Climate Change Mitigation Technologies (CCMT) related to buildings	Y02B
Greenhouse gases (GHG) capture and storage	Y02C
CCMT related to energy generation, transmission or distribution	Y02E
CCMT in the production or processing of goods	Y02P
CCMT related to transportation	Y02T
CCMT related to wastewater treatment or waste management	Y02W
Smart grids	Y04S
Technologies for adaptation to climate change	Y02A
CCMT in information and communication technologies	Y02D

Source: Elaborated by the author based on CPC scheme and CPC definitions

Chapitre 2

What are the drivers of eco-innovation? Empirical evidence from French start-ups²⁴

2.1 Introduction

In a context of natural resource scarcity, environmental degradation, and wasteful consumption, urgent solutions are required. Governments and society have recognized the crucial role of sustainability. To this end, achieving the objectives of sustainable development involves the participation of all economic actors. Companies are also participating in these environmental and societal changes, and respond to social demand by developing processes and solutions capable of offering greener goods and services. These changes are an important strategic concern for manufacturers in terms of positioning their products in highly competitive markets. Some companies are looking to take advantage of the niche opportunities created by the transition towards sustainable development: indeed, an OECD (2010) survey revealed that environmental challenges are seen in many countries as a new opportunity for competitiveness. In addition, in the medium term, the scarcity of fossil resources and the increase in carbon taxation will lead to an increase in the prices of these resources, which might weaken the competitiveness of actors and territories not prepared for transition (Deboutière and Georgeault, 2015).

We notice, therefore, the emergence of new, more resilient and future-oriented economic models. Among these models, we can cite the circular economy, the collaborative economy or the functionality economy (ADEME, 2004). The production system has begun to adopt greener and renewable energy sources. Green entrepreneurship is also an actor in this transition. In this context,

²⁴ This chapter is a joint work with R. Abdesselam and P. Renou Maissant, it has been presented at the SMTDA 2020 conference.

the introduction and adoption of new products, processes and practices that reduce or limit environmental impacts can play an important role (Geels, 2010). Thus, given that they allow the development of solutions which induce a positive impact on at least one of the fundamental pillars of sustainable development, i.e. the economy (energy efficiency for example), society, and the environment, start-ups must be a major concern of public policy and innovation policy. Start-ups have features that make the development of eco-innovations easier: they have the flexibility to adapt to changes in their activity (Aragón-Correa et al., 2008; Keskin et al., 2013), they display a spirit of risk taking, and they also have a key role in bringing radical innovations to the market and in developing breakthrough eco-technologies (Demirel et al., 2019). But so far, we know very little about the distinctiveness of the innovation strategy of this type of firms.

At the European level, several incentives have been set up to encourage the creation of green SMEs. Among these initiatives there are the Small Business Act and the Green Action Plan which consist in supporting SMEs in order to turn environmental problems into opportunities.

Since 2010, as part of the “Programme d’Investissement d’Avenir (PIA)”, the French environment and energy management agency (ADEME) has provided a total of 93 million euros in grants to SMEs carrying out projects that respect the environment (ADEME, 2018). In order to face environmental challenges, France is engaged in structural transformation of its economy. The legislative framework that regulates this change is the law on energy transition for green growth. According to a report by the Ministry for Ecological Transition, this is an opportunity for companies to create new activities, jobs and wealth while playing a crucial role in achieving sustainable development objectives (MTES, 2020).

The French economy is largely based on Small and Medium-Sized enterprises (SMEs). The number of French SMEs represent 99,7% of the total number of enterprises. A majority of them (3,67 millions) are microenterprises (MIC), generating 1/3 of the added value and employing 46% of the workforce (MTES, 2020). The empirical literature has highlighted the importance of these companies in the economy, whether in terms of job creation (Birley, 1986) or in terms of innovation (Drucker, 1985), and their impact on the environment is significant. Thus, the study of eco-innovative start-ups is relevant in order to better guide these public policies: since they are an important part of the problem, they could also be part of the solution (Kiefer et al., 2019). Although the individual impact of each company is low compared to the role that a large company could play in reducing pollution, the cumulative impact of all SMEs may be considerable (EC, 2020). Despite the worldwide increase in the number of green start-ups in recent years, their representation in the total number of start-ups remains low. In fact, at the start of 2020, Frenchtech identified 14,189 microenterprise start-ups in France, of which 482 were cleantech start-ups, comprising a share of 3.4%.

In the academic literature, the study of eco-innovative firms has attracted the attention of several researchers who have studied the determinants of eco-innovation in depth (see Del Río et al., 2015 for a review). The study of the typologies of firms, principally SMEs, focuses on the eco-innovative nature of the firm without taking into account the entrepreneurial nature of the activity. Moreover these studies do not distinguish between established firms and newly-created firms (“born to be green” firms²⁵). For the elaboration of the typology, these studies are based on three main factors related to the determinants of environmental innovation: technology push, market pull and regulation. Some of them go further in their analysis by taking into account the factor of cooperation and the diffusion of knowledge (Castellacci and Lie, 2017; Doloreux and Kraft, 2019). Another area of the literature is concerned with studying the typologies of sustainable entrepreneurship. The main factors considered in this literature are the motivation of the entrepreneur (economic or environmental values) as well as the main orientation of the firm (Linnanen, 2002; Schaltegger, 2002; Schaltegger and Wagner, 2011); however, the eco-innovation aspect is marginal.

The purpose of this paper is, firstly, to study the distinctiveness of eco-innovative start-ups compared to non-eco-innovative start-ups based on two themes: human capital characteristics and environmental policy. To do so, we apply a decision-making model, namely a discriminant analysis (DA). Secondly, a typology of eco-innovative start-ups has been developed using a hierarchical ascendant classification (HAC) based on five main themes: financial resources, external knowledge, eco-innovation type, motivation and environmental orientation. The aim is to examine whether a variety of profiles emerges among the sample of eco-innovative start-ups. Moreover, the typology makes it possible to identify the different incentives that affect each category (Nikolaou et al., 2018). The taxonomic study is an appropriate method for this case because it constitutes an intermediate approach between analyses based on various individual cases and the generality of macroeconomic studies (sector or country level) (Marin et al., 2015). Furthermore, the study of the specificities of eco-innovators and the understanding of their diverse patterns, in a context of environmental challenges, is of high relevance for developing public policies. The main information needed to carry out this study in the context of start-ups is not available in the existing datasets; for this reason, the analysis is based on a survey of 120 eco-innovative and non-eco-innovative French start-ups that we conducted in 2019.

The theoretical framework is based on literature that combines the resource-based view and the evolutionary perspective to categorize the drivers of eco-innovation into internal and external

²⁵ This concept is used by Demirel et al. (2019) to qualify new businesses created with a sustainable approach to entrepreneurship.

factors (del Río González, 2009; del Río et al., 2016; Demirel and Kesidou, 2011; Sáez-Martínez et al., 2016). In our case factors internal to the firm refer, for instance, to financial resources and environmental orientation (for more details, see figure 2.1). Meanwhile, external factors refer to cooperation. We complete this framework with some aspects of the entrepreneurship literature (Casson, 2005).

The results of the DA show that eco-innovative start-ups differ in the skills acquired by the entrepreneur, in particular through environment-related studies and professional experience. The existence of “command and control” environmental instruments such as standards and prohibitions differentiate eco-innovators from non-eco-innovators. However, “economic instruments” such as environmental taxes do not distinguish the two groups of start-ups. Furthermore, the presence of a CSR policy (whether formalized or not) is an important differentiating factor. The results of the HAC show that there is a diversity of profiles of eco-innovators. In fact, firms cluster into five main profiles: senior entrepreneurs with environmental concerns, necessity entrepreneurs without environmental concerns, entrepreneurs with ecological awareness, and market-driven opportunists without environmental concerns. They also exhibit different eco-innovation drivers. We have shown empirically that different types of eco-innovators do not have the same difficulties in accessing funds. The paper concludes that policies must be designed by considering the distinctiveness of each profile.

The contribution of this study is manifold. A) We point out the particularities of eco-innovators by considering their human capital drivers, which in turn highlights the importance of entrepreneurial characteristics for spurring eco-innovation, notably the prior knowledge of the entrepreneur. B) We identify five categories of eco-innovators: the typology is based on relevant drivers for start-ups, such as financial resources and motivation. We point out the most relevant drivers of each type and we examine the form of eco-innovation (incremental, radical, frontstage and backstage) developed by each type. Furthermore, we suggest the policy measures to be adopted according to the type of eco-innovator. C) The existing studies on eco-innovators focus on the case of SMEs without distinguishing established firms from start-ups. They do not take into account the distinctiveness of newly created start-ups, which are a special case because of the ease with which they can adapt their business plans to environmental issues. They also do not investigate the role that the entrepreneur might play. This study goes beyond the existing studies on SMEs by providing firm new evidence for the determinants of eco-innovation by implementing an entrepreneurship approach and by focusing on the case of start-ups. To our knowledge, no other research is devoted to the empirical study of the typologies of eco-innovative start-ups. There is, therefore, a need to better understand the eco-innovative nature of green start-ups to see to what extent they could contribute to tackling

climate change. D) Finally, the originality of the data collected through a survey of start-ups and the diversity of the variables considered constitutes a significant contribution to the literature.

Our paper is structured as follows: Section 2 explains some concepts and gives a literature review. Section 3 presents the questionnaire and data collection. The methods and the results of the analysis are provided and discussed in Section 4. Section 5 concludes and gives policy recommendations.

2.2 Literature review

In what follows, we will first define eco-innovation and its typologies, then we will present the determinants of eco-innovation from different perspectives.

2.2.1 Definition of eco-innovation

Eco-innovation is a complex concept, and it is important to delineate its boundaries. In this study we adopt the definition of the European Commission report: “Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resource use (including energy use) compared to relevant alternatives” (Kemp and Pearson, 2007). Radical eco-innovation is a completely new product and process that causes a change in production, consumption or organization patterns. Incremental eco-innovation is a simple improvement, characterized by a low degree of innovation and a moderate change in the market or customer value (Garcia and Calantone, 2002). The frontstage eco-innovation (also called front-end) is the initial phase of idea generation, whereas backstage eco-innovation (also known as back-end eco-innovation) is the product development phase.

2.2.2 Internal and external drivers based on market, technology and regulation

The general theory of innovation distinguishes two important factors that stimulate investment in innovation (technology push, market pull). This also applies to eco-innovation, however, specific factors play a determining role, in particular environmental policies (both in the form of command and control and market-based instruments) (Horbach, 2008; Porter and Van der Linde, 1995).

A relevant classification of the drivers of eco-innovation has been proposed by (Horbach, 2008) that includes the three factors mentioned above: technology push, market pull and regulatory push/pull. Empirical findings related to the importance of market pull factors for stimulating eco-

innovation differ. Some studies suggest that demand factors such as increased market share and higher consumer demand for environmentally-friendly products have a positive effect on the firm's decision to undertake eco-innovations (Kesidou and Demirel, 2012; Triguero et al., 2013). Others argue that market pull factors play a limited role in spurring eco-innovation because eco-friendly products are still expensive (Rehfeld et al., 2007). Moreover, the effect of the market pull is limited in countries with low environmental awareness and willingness to pay (del Río et al., 2016).

The environmental policy factor (regulatory push/pull effect)²⁶ comprises all public measures to reduce the environmental impact. According to Rennings (2000), regulation is important in addressing the double externality problem associated with eco-innovation. Previous studies have found that different regulation instruments have an influence on the decision to undertake eco-innovation (Belin et al., 2011; Rehfeld et al., 2007). Stringent regulations can stimulate investment in eco-innovation (Kammerer, 2009).

The technology push factor is associated with technological capabilities which mainly combine human capital and physical capital (Triguero et al., 2013). High technological capacities can lead to new eco-innovations (Belin et al., 2011; Horbach, 2008). To acquire these capabilities, investment in R&D and the training of employees is of high importance (Cainelli et al., 2015; Horbach et al., 2012). The literature has also emphasized the importance of the “external knowledge” factor. Eco-innovations are characterized by a higher level of risk, uncertainty and novelty (Belin et al., 2011), and they are also more complex (De Marchi, 2012). Because of this, they are highly dependent on knowledge and information which cannot be satisfied only internally. The existing literature points out that eco-innovation is more cooperation-intensive than other innovations. Thus, it is crucial for eco-innovation that there is cooperation between heterogeneous partners such as firms (De Marchi, 2012; Horbach, 2008), clients, distributors, suppliers (Buttol et al., 2012; Cainelli et al., 2012; Cainelli and Mazzanti, 2013), universities (Cainelli et al., 2012; Triguero et al., 2013) and governmental partners (Doblinger et al., 2019).

²⁶ The literature distinguishes two categories of public policy instruments (Command and control and Economic instruments). Command and control are regulatory instruments such as bans, emission volume limits and technical requirements. Economic instruments consist of retaining a price on negative externalities. They are less flexible because they leave to the agents the choice of the least cost strategy.

The determinants of eco-innovation at the firm level have been approached in different ways by using different theories – among others, the resource-based view and evolutionary theory.²⁷ The studies based on these theories suggest another classification of the drivers of eco-innovation by distinguishing internal factors from external factors. Earlier literature has focused on the external factors; however, some authors have pointed out the shortcomings of these studies due to their inability to explain the firms' internal stimuli. External factors are not sufficient to explain eco-innovation decisions at the firm level (Demirel and Kesidou, 2011; Kesidou and Demirel, 2012; Triguero et al., 2014); they must be supplemented by factors internal to the firm. In order to address these shortcomings, there has been increasing interest in the resource-based view, which emphasizes the importance of the internal resources of firms. These resources can be classified into three categories: physical capital (physical technology, equipment, location), human capital (managers' and workers' skills) and organizational capital (Barney, 1991). By contrast, the evolutionary theory states that innovation is a complex and dynamic system influenced by both internal and external factors. Recent studies based on this theory have taken into account both internal and external factors (Cainelli et al., 2015; Demirel and Kesidou, 2011; Triguero et al., 2014).

2.2.3 Internal and external drivers based on entrepreneurship theory

Over the past decade, several studies have highlighted the particularity of eco-innovation within SMEs. This question has started to arouse increasing interest among researchers (for more details, see Pacheco et al., 2018, 2017). SMEs have the particular feature of innovating differently (Bos-Brouwers, 2009; Klewitz and Hansen, 2014) and play a central role in the transition towards a sustainable economy (Hall et al., 2013). The study of the internal drivers of environmental practices of SMEs also draws on entrepreneurship theory,²⁸ especially sustainable entrepreneurship.²⁹ Sustainable entrepreneurs have specific business and organizational motivators and skills (Bocken,

²⁷ Other researchers have analysed the determinants of eco-innovation by using other theories such as stakeholder theory, theory of planned behaviour, and institutional theory. These theories are not the subject of this study (for more detail, see the works by Hazarika and Zhang, 2019; Munodawafa and Johl, 2019).

²⁸ The theory of entrepreneurship argues that a firm's strategic direction is closely related to the decision making of the entrepreneur, where the latter is responsible for the gathering and analysing of available information to make important business decisions; the theory states that the entrepreneurial capabilities are a firm's main human resource (Casson 2005).

²⁹ Sustainable entrepreneurship refers to "entrepreneurial activities that contribute positively to sustainable development and the objectives derived from it" (Kuckertz and Wagner, 2010). Several other concepts are used to designate the relationship between entrepreneurship and sustainable development, such as ecopreneurship, social entrepreneurship, or green entrepreneurship. (For more details see Gast et al., 2017.)

2015). Sustainable entrepreneurship is characterized by the entrepreneur's specific values and culture (Anderson, 1998). Thus, the main factors discussed are related to the individual entrepreneur. The importance of the sustainability intention and orientation of the entrepreneur is highlighted in many articles (Linnanen, 2002; Schaltegger, 2002; Schaltegger and Wagner, 2011). Linnanen (2002) shows that green entrepreneurs have several characteristics in common with traditional entrepreneurs; the main difference is the important role of ethical values. Hoogendoorn et al. (2020) show that environmental value creation has a positive effect on the innovativeness of the start-ups. Moreover, Patzelt and Shepherd (2011) found that the entrepreneur's prior knowledge is also relevant.

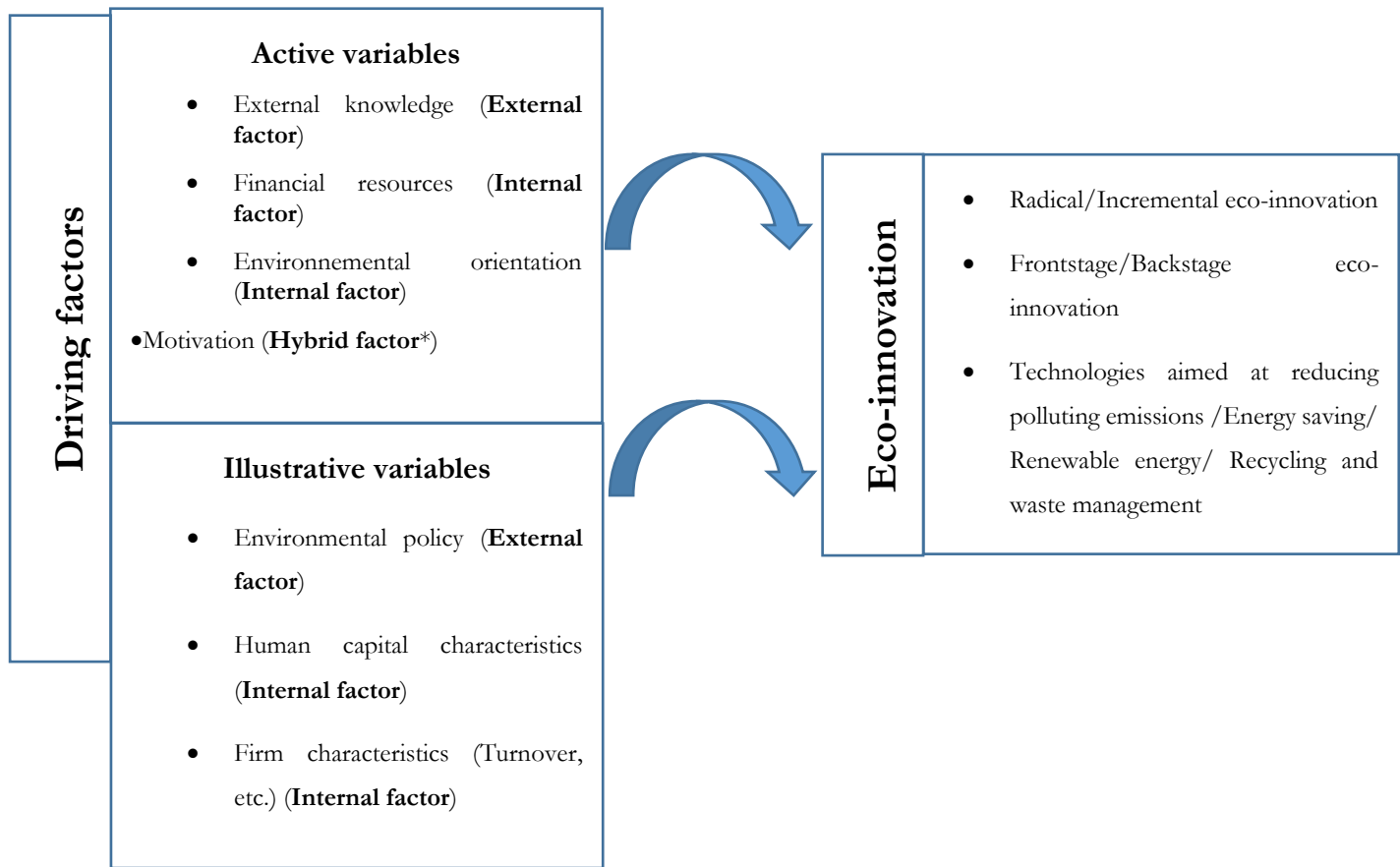
While studies investigating the diverse patterns of eco-innovative start-ups are relatively scarce, the different categories of sustainable entrepreneurs have received further attention in the literature. Muñoz and Dimov (2015) have used individual factors related to the entrepreneur (knowledge, orientation, intention) and external factors related to perceived social support and business support. They identified two paths: conformist "sustainability conveyors" operate in a social context characterized by the abundance of environmental values and convictions, their motivation is to comply with existing standards and values; whereas "insurgents" emerge in a context characterized by a lack of environmental convictions. The latter are entrepreneurs who find inspiration in personal values and must operate against defined standards. Based on internal organizational capabilities, Aragón-Correa et al. (2008) established a classification of SMEs. Being mainly interested in the level of proactivity³⁰ in the implementation of environmental practices, they distinguish three categories: reactive, pollution prevention and leadership. However, in most of these studies there is only an implicit reference to eco-innovation. They focus, rather, on corporate environmental practices. Bergset and Fichter (2015) have established a conceptual typology of green start-ups based on a literature review. They focus on the factors that play an important role in the financing decisions of investors, including sustainability motivation and business qualification. They distinguish five categories of green start-ups: the alternative start-up, the visionary start-up, the inventive start-up, the "ecopreneurial" start-up, and the unintentionally green start-up. The latter is characterized by highly innovative entrepreneurs, is exposed to high risks and requires high levels of capital. Walley and Taylor (2004) have presented a theoretical typology of eco-entrepreneurs based on their individual orientation and the intensity of external influence. They distinguish between innovative opportunist, visionary champion, ethical maverick and ad hoc "enviropreneur". The innovative opportunist has a purely economic objective and is greatly influenced by external pressures.

³⁰ Strategic proactivity is defined as a firm's ability to initiate changes in its strategic policies regarding its entrepreneurial, engineering, and administrative activities, rather than reacting to events (Aragón-Correa, 1998).

To our knowledge, there are only four studies that have been devoted to the typologies of SMEs by studying eco-innovation. Triguero et al. (2013) study the diversity of eco-innovators based on eco-innovation intensity. Their study is based on the triangle model of van Dijken which considers three factors: business skills, environmental orientation, and network involvement. They distinguish between leaders, followers, loungers and laggards. Leaders are highly eco-innovative, while laggards have a low level of eco-innovation and reduced environmental impact. Doloreux and Kraft (2019) and Castellacci and Lie (2017) study the main determinants of different types of eco-innovations. Doloreux and Kraft (2019) measure the intensity of eco-innovation by the diversity of eco-innovations developed (products and processes). They identify eco-innovation laggards, product-oriented eco-innovators, process-oriented eco-innovators, and fully-integrated eco-innovators. Castellacci and Lie (2017) identify the different determinants according to the types of eco-innovations. They distinguish between CO₂-reducing, waste reducing, recycling and pollution-reducing innovators. Sáez-Martínez et al. (2016) distinguish between technology-driven innovators, traditional firms, market-driven innovators, and sporadic innovators.

These studies focus on the case of SMEs without distinguishing the established firms from the newly created start-ups. They do not take into account the distinctiveness of start-ups, which constitute a special case because of their ease of adapting their business plan to environmental issues. They are also not interested in the role that the entrepreneur might play. We introduce factors that may be specific to the case of start-ups, including human capital characteristics such as the financial resources and the prior knowledge of the entrepreneur (measured by environment-related education and experience). We also consider the environmental orientation of the firm and the type of the eco-innovation developed (incremental, radical, frontstage and backstage) (see figure 2.1).

Figure 2.1 Theoretical framework



*Motivation can be related to internal and external factors

Source: Own elaboration

2.3 Data: development of a survey

2.3.1 Questionnaire design and development

Unfortunately, the European and French censuses of start-ups do not provide details of their innovation strategies, financing or growth. Data on this type of businesses is therefore not very accessible. Indeed, all start-ups are SMEs, but not all SMEs are start-ups, differing in particular in terms of their growth and their vision (Steigertahl and Mauer, 2018). The main information needed to carry out this study in the context of start-ups is not available in the existing datasets; for this reason we elaborated and conducted our own survey.

Our questionnaire is structured in four parts: the first part gathers a set of general information on the company (year of creation, turnover, etc.); the second part is devoted to the human capital characteristics of the firm; the third part relates to non-environmental innovation activity; and the fourth part covers the questions related to the eco-innovation activity. We chose to separate non-environmental innovation activities from eco-innovation activities for two reasons. First, to be able to identify the companies that develop the two types of innovation (environmental and non-environmental); second, to identify the specific drivers of eco-innovative and non-eco-innovative start-ups. A start-up is considered to be eco-innovative if the answer to the question, “During the last five years, has your company introduced or developed one or more environmental innovation(s)?” is “Yes”; it is considered non-eco-innovative if the answer is “No”. Appendix 2.1. lists the detailed questions included in the questionnaire. Two main criteria were used to select the sample: the start-up has an innovation activity, whether environmental or not; and the start-up is less than 12 years old. The questionnaire contains a section devoted to the profile of the entrepreneur, so the founders of the start-ups were questioned. This decision to question the founders was also based on the fact that the founders have a better knowledge of the start-up and the motivations behind its creation.

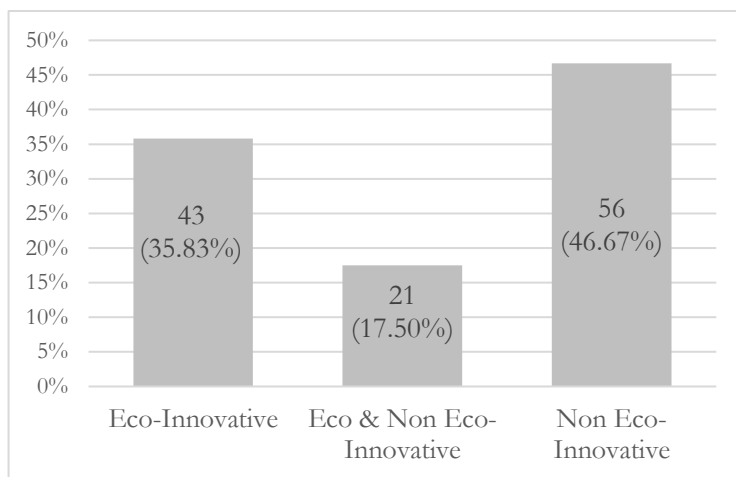
The survey was conducted face-to-face and by email to start-ups in France, from March 2019 to February 2020. The face-to-face survey was carried out at the “Change Now” summit and the “International cleantech week meeting”. Twenty-five questionnaires were collected through the face-to-face survey. The sample was completed by sending the questionnaire by email to the firms listed as winners of the innovation contests: “I-Nov”, “I-lab” and “Prix pépite pour l’entrepreneuriat étudiant”. More than 700 companies were contacted and 124 questionnaires were returned by email. A total of 149 responses were collected, representing a response rate of 21%. Among them, 29 responses were invalid, either because they did not meet the selection criteria (the age of the firm exceeded 12 years and/or the start-up was not concerned with innovation activity), or because they were non-profit associations or the responses were incomplete. There remained a total of 120 valid responses, which were used for this study. The response rate is considered satisfactory, especially given that it was company founders who were requested to participate in the survey. Similar response rates have been recorded in the literature for the use of non-mandatory surveys (Doloreux and Kraft, 2019). The personal characteristics of the respondent were used to characterize the firm in the case of multiple-founder firms.

2.3.2 Sample characteristics

Figure 2.2 shows the distribution of the 120 start-ups according to their type of innovation: 21 are both eco- and non-eco-innovative. First, we will determine what differentiates eco-innovative firms

(64 start-ups) from non-eco-innovative firms (56 start-ups) according to different themes. Second, we will establish a typology of eco-innovative firms according to their entrepreneurial characteristics.

Figure 2.2 Distribution of firms by type of innovation



Source: Own elaboration

Table 2.1 Sample characteristics

Start-ups characteristics	Number of firms	Frequency (%)
Sector		
Services, retail and waste management	12	10
Professional, scientific and technical activities	60	50
Manufacturing	20	17
Information and Communication	28	23
Total	120	100
Age		
0-5 years	95	79
6-12 years	25	21
Total	120	100
Turnover		
[0; 100 000]	50	42
[100 001; 500 000]	25	21
[500 001; 1000 000]	11	9
More than one million	5	4
The firm has not yet started to commercialize the products	29	24
Total	120	100
Employees		
0-5	83	69
5-10	21	18
10-65	16	13
Total	120	100

Table 2.1 provides detailed information on the final sample. The sample includes 120 start-ups mainly belonging to the following sectors: professional, scientific and technical activities, manufacturing, information and communication, services, retail and waste management. Since this sample was targeted as nascent entrepreneurs, most firms were established less than five years ago (79%), 87% have less than 10 employees, and 24% have not yet started to market their products.

2.4 Methodology and empirical results

Our study is based on the implementation of multidimensional data analysis methods. First, we used a decision-making model, namely discriminant analysis (DA) (Celeux and Nakache, 1994; Huberty, 1994), aiming to discriminate the drivers of eco-innovative firms from those of non-eco-innovative firms. Then, we used hierarchical ascendant classification (HAC) (Lebart et al., 2000; Saporta, 2006) to establish a typology of the 64 eco-innovative start-ups according to their entrepreneurial characteristics.

2.4.1 The differentiating drivers of eco-innovative and non-eco-innovative start-ups

DA is performed on each of two sets of explanatory variables associated with human capital and environmental themes. The aim is to study their effect on the type of eco-innovation start-ups. Discriminant analysis is a multivariate model which makes it possible to study the effect of a set of explanatory variables of a homogeneous theme on a target variable, in our case, eco-innovation. The DA approach is close to that of regression. In each case, we try to explain or predict a dependent variable by a linear combination of explanatory continuous variables. In DA, the explained or dependent variable is qualitative, thus 'DA' specifically means DA on continuous explanatory variables. When the explanatory variables are qualitative, the researcher first applies multiple correspondence analysis (MCA), then carries out DA on the principal components of the MCA as continuous explanatory variables. This methodological chain of data analysis methods is known as DA on qualitative variables.

The analysis is carried out on two groups of start-ups: eco-innovative and non-eco-innovative. The first group contains 64 start-ups and the second group contains 56 start-ups. The dependent variable is the qualitative variable "eco-innovation" with two modes: groups of eco-innovative start-ups and groups of non-eco-innovative start-ups. We use explanatory variables from two homogeneous

themes, human capital characteristics and environmental policy. The former includes the variables related to gender, age, educational level, obtaining a degree related to environmental studies, situation before creation, professional experience related to the environment, number of years of this experience and the existence of other co-founders. The latter consists of the following variables: environmental regulations (standards, permissions, prohibitions), taxes on inputs (energy), taxes on polluting emissions, lack of environmental policy instruments, and Corporate Social Responsibility (CSR) policies. The purpose is to highlight the conditions—for each of the human capital characteristics and environmental policy themes—which best differentiate eco-innovative firms from non-eco-innovative firms.

2.4.1.1 Human capital characteristics

The main results of the DA are summarized in table 2.3, which presents the coefficients of the discriminant function, and the modalities of the eight variables that discriminate between eco-innovative firms and non-eco-innovative firms.

The model as a whole is significantly discriminating. In fact, the probability (p-value = 0.001) is less than the classical error risk $\alpha = 5\%$. Therefore, human capital characteristics have a significant effect on the creation of eco-innovative start-ups. Table 2.2 summarises the percentage of correctly classified and misclassified start-ups in each group. The percentage of correctly classified start-ups (69.17%) measures the quality of the discriminant model, the error rate is 30.83%: the model is satisfactory. The conditions which discriminate between the two groups of start-ups are those with a probability lower than the error risk chosen (p-value $< \alpha = 5\%$).

Table 2.2 Classification table for the Human capital explanatory theme

Original groups	Classification counts and (Percentages)		
	Correctly classified	Misclassified	Total
Eco-innovative Start-up	43.00 (67.19)	21.00 (32.81)	64.00 (100.00)
Non-eco-innovative Start-up	40.00 (71.43)	16.00 (28.57)	56.00 (100.00)
Total	83.00 (69.17)	37.00 (30.83)	120.00 (100.00)

Table 2.3 Discriminant analysis results of Human capital explanatory theme

<i>Linear discriminant analysis model: "Human capital" theme</i>					
Variable Number	Modality	Parameter estimates		Standard Error	Student T-Test
		Disc. Fonction	Regression		
Eco-innovative start-up:					
1 m2	Man	0.1382	0.0577	0.1345	0.43
2 m1	18-25 years	3.1930	1.3334	1.0821	1.23
2 m2	26-35 years	0.4807	0.2007	0.3192	0.63
2 m4	45-54 years	3.4304	1.4325	0.7977	1.80
3 m1	BEP-CAP, no diploma	6.8198	2.8479	1.9808	1.44
3 m3	Bachelor	1.0140	0.4234	1.1261	0.38
3 m4	Master- Engineer	2.2247	0.9290	0.2642	3.52**
4 m2	Yes-Env-Diploma	6.4182	2.6802	1.0482	2.56**
5 m1	Others (retired –lib.prof) Company manager	0.2449	0.1023	1.0907	0.09
5 m3	experience	1.5593	0.6511	0.6726	0.97
5 m4	Student	2.3594	0.9852	0.5953	1.65
6 m2	Yes-Env-Prof-Experience	4.2474	1.7736	0.7526	2.36**
7 m1	1-5 years	1.2187	0.5089	1.2149	0.42
7 m2	5-10 years	0.1152	0.0481	1.6194	0.03
7 m4	Over 10 years	10.9668	4.5796	1.5008	3.05**
8 m2	No co-founder	4.0698	1.6995	0.8325	2.04*
Non-eco-innovative start-up:					
1 m1	Woman	-0.5528	-0.2308	0.5379	-0.43
2 m3	36-44 years	-3.3919	-1.4164	0.4749	-2.98**
2 m5	Over 55 years	-0.2531	-0.1057	0.5996	-0.18
3 m2	PhD	-5.1100	-2.1338	0.5072	-4.21**
4 m1	No-Env-Diploma	-0.5204	-0.2173	0.0850	-2.56**
5 m2	Job seeker	-3.7378	-1.5609	0.7147	-2.18*
5 m5	Salaried employee	-0.5754	-0.2403	0.3348	-0.72
6 m1	No-Env-Prof-Experience	-0.6597	-0.2755	0.1074	-2.57**
7 m3	No professional experience	-0.6068	-0.2534	0.1075	-2.36**
8 m1	Yes co-founder	-1.0710	-0.4472	0.2191	-2.04*
INTERCEPT		0.226456	0.00000		
D2 = 0.84921 T2 = 25.36314 p-value = 0.001					
The overall rate of misclassification: 30.83%					

Significance level α : ** $\alpha \leq 1\%$; * $\alpha \in]1\%, 5\%$]

Among the eight explanatory variables introduced into the model, only the variable gender is not discriminating. All the other variables effectively differentiate the two groups of start-ups.

Thus, we can characterize eco-innovative start-ups as firms created by single people, without co-founders, who have a Master's level diploma in Engineering and have more than 10 years of professional experience in an environmental field.

As to non-eco-innovative start-ups, these are companies created with co-founders. The manager tends to be aged between 36 and 44 years, and was a jobseeker before creating the company; they are highly educated people without any professional experience related to the environment.

2.4.1.2 Environmental policy

Table 2.5 presents the results of the linear Fisher's function of the DA environmental policy theme. The model as a whole is significant (p -value = 0.001 < 5%). 68.33% of companies are correctly classified by the model, the error rate is 31.67%, and so the model is satisfactory (See table 2.4).

Among the five variables introduced into the model, only two explanatory variables—taxes on inputs (energy) and taxes on polluting emissions—are not significantly discriminating. All the other variables distinguish the two groups of start-ups effectively. Indeed, the existence of environmental regulations and a CSR policy (whether formalized or not) differentiate the two groups of start-ups. Non-eco-innovative start-ups are characterized by the absence of environmental regulations and a CSR policy. Eco-innovative start-ups are subject to incentives provided by environmental policy instruments and they are characterized by the existence of voluntary environmental practices such as CSR.

Environmental instruments commonly known as “command and control”, such as emission or product standards, prohibitions and authorizations issued by administrative authorities, differentiate between eco-innovative and non-eco-innovative start-ups. These instruments may, for example, be related to facilities classified for environmental protection (ICPE)³¹ subject to authorization in order to exercise their activity. Non-eco-innovative start-ups are distinguished by the absence of command and control instruments. The environmental instruments commonly named “economic instruments” such as taxes on polluting emissions and inputs have not proven to be elements that separate the two groups. The creation of eco-innovative start-ups can be stimulated by the need to comply with existing or anticipated environmental standards and authorizations. It can also be spurred by a desire to conform to the principles of sustainable development, in particular by implementing a CSR policy.

³¹ Due to the risk it presents for the environment, involving inconveniences for the neighbourhood, health, safety, agriculture, or the protection of nature, such activities are subject to specific regulations, in particular in terms of authorization.

Table 2.4 Classification table for the Environmental policy explanatory theme

Original groups	Classification counts and (percentages)		
	Correctly classied	Misclassified	Total
Eco-innovative Start-up	38.00 (59.38)	26.00 (40.63)	64.00 (100.00)
Non-eco-innovative Start-up	44.00 (78.57)	12.00 (21.43)	56.00 (100.00)
Total	82.00 (68.33)	38.00 (31.67)	120.00 (100.00)

Table 2.5 Discriminant analysis results of Environmental policy explanatory theme

Linear discriminant analysis model: “Environmental policy” theme					
Variable Number	Modality	Parameter estimates		Standard Error	Student T-Test
		Disc. Fonction	Regression		
Eco-innovative start-up:					
1 m2	REG-Yes selected	1.9324	0.8185	0.2960	2.77**
2 m2	TI- Yes selected	10.0794	4.2694	4.7391	0.90
3 m2	TPE-Yes selected	12.7902	5.4176	4.6184	1.17
4 m1	NONE-Not selected	1.7184	0.7279	0.2839	2.56**
5 m2	NA	13.8058	5.8478	4.6846	1.25
5 m3	YES-CSR	2.6015	1.1019	0.490	2.25*
Non-eco-innovative start-up:					
1 m1	REG-Not selected	-1.2012	-0.5088	0.1840	-2.77**
2 m1	TI-Not selected	-0.0847	-0.0359	0.0398	-0.90
3 m1	TPI-Not selected	-0.1075	-0.0455	0.0388	-1.17
4 m2	NONE-Yes selected	-1.3593	-0.5758	0.2246	-2.56**
5 m1	NO-CSR	-2.5316	-1.0723	0.4339	-2.47**
CONSTANTE		0.130223	0.000000		
D2 = 0.69044 T2 = 21.34278 p-value = 0.001					
The overall rate of misclassification : 31.67%					

Significance level α : ** $\alpha \leq 1\%$; * $\alpha \in]1\% , 5\%$]

2.4.2 Typology of eco-innovative start-ups according to their entrepreneurial characteristics

Secondly, an HAC according to the Ward criterion³² is performed on the 64 eco-innovative start-ups based on their entrepreneurial characteristics related to access to finance, access to external knowledge (cooperation, exchange of ideas), the type of eco-innovation developed (radical, frontstage,

³² Generalized Ward's Criteria, i.e. aggregation based on the criterion of the loss of minimal inertia.

etc.), motivation and environmental orientation (implementation of an environmental management system, analysis of the environmental impacts of products, etc.). Their status in the analysis is called active variables. They are used to build the typology and to characterize the most homogeneous and distinct eco-innovative start-up classes possible. According to the similarities of the start-ups relative to these active variables, we establish a typology of five homogeneous classes of eco-innovative start-ups.

All the other variables of the questionnaire can be introduced as illustrative variables in the HCA. These supplementary variables do not participate in the characterization of the typology; they are used a posteriori to attempt to describe the eco-innovative start-up classes previously characterized by the active variables.

Table 2.6 shows the significant results of the analysis.

Class 1: Senior entrepreneurs with environmental concerns

This class represents 17.19% of the sample. These start-ups are developing radical eco-innovations. The project has been developed from the idea stage so that the environmental aspect is considered throughout the innovation. These innovations are initially designed in such a way that they reduce environmental impact, in particular through analysis of the environmental impacts of products. The project is credible and attractive, which enables these start-ups to access grants, in particular those from national organizations. They are also characterized by the important role played by the personal financial contribution of the founder. Interest in the environmental aspect is high, which can be observed in particular through the importance given to training employees on subjects related to environmental issues. Their purpose is not to reduce the costs but rather to provide a radical solution to an environmental problem. The start-ups of this class tend to have three and more co-founders and the leader is aged 55 or over.

Start-ups that develop radical innovations are characterized by the presence of several founders. This could be the source of a diversity of skills (management, technical, accounting, financial, legal, commercial). Several studies have highlighted the positive effect of the founder's involvement in other functions (CEO, president, manager, etc.) (Adams et al., 2009; Li and Srinivasan, 2011). Fahlenbrach (2009) examines the investment decisions of founder CEOs and finds that they invest more in research and development. Chen et al. (2012) find that multi-founder firms are more valuable than all other types of firms (including family firms and single-founder firms).

Table 2.6 Significant results of the hierarchical classification

Theme	Cluster 1: Senior entrepreneurs with environmental concerns	Cluster 2: Necessity entrepreneurs without environmental concerns	Cluster 3: Entrepreneurs with ecological awareness	Cluster 4: Market-driven opportunist entrepreneurs without environmental concerns	Cluster 5: Opportunist leaders
Actives Variables					
Financial resources	+ Fund raising + Funding through personal contribution + Grants for environmental innovation activity + National grants	- Fundraising	- Fundraising - Grants for environmental innovation activity - Grants from national organizations - Grants from local authorities	- Grant from the European Union	+ Fundraising + Private investors or venture capital funds + Regional grant
Eco-innovation Type	+ Radical eco- innovations - Backstage eco- innovation	-Technologies aimed at reducing polluting emissions	+ Incremental eco- innovation + Backstage eco-innovation - R&D activity	None	+ Technologies aimed at reducing polluting emissions (CO ₂ , NO ₂ , etc.) + Adoption of a new innovation by the start-up + Frontstage eco-innovation + Internal R&D
Environmental orientation	+ Environmental benchmarking (sometimes) + Environmental impact assessment + Employees Environment related training	+ Eco-Brainstorming (Rarely) + Frontstage- Environmental impact assessment (Rarely) - Setting environmental goals	None	+ Not concerned by environmental management + Eco-conception (Never) - Frontstage: Setting environmental goals	+ Environmental Benchmarking (Often) + Eco-Brainstorming (Often) + Frontstage- Environmental impact assessment (Often) + Eco-conception (Often) + Environmental management and audit system + Setting environmental goals
Motivation	- Cost savings	- Increasing demand for green products	+ Ecological awareness - Cost savings	+ Increasing demand for green products	+ Cost savings - Ecological awareness
Access to external knowledge	None	None	- Cooperation with universities	- Cooperation - Exchange of ideas related to the environment through meetings	+ Cooperation with universities or higher education institutions + Cooperation with suppliers + Cooperation with consultants, commercial or private laboratories + Cooperation with other companies of the same group or the retail network

Table 2.6 Significant results of the hierarchical classification (Continued)

	Cluster 1: Senior entrepreneurs with environmental concerns	Cluster 2: Necessity entrepreneurs without environmental concerns	Cluster 3: Entrepreneurs with ecological awareness	Cluster 4: Market-driven opportunist entrepreneurs without environmental concerns	Cluster 5: Opportunist leaders
Illustrative variables					
	+Three or more co-founders + Founder's age: 55 and over	+ No co-founder + Job-seeker founder	+ Turnover <100,000 € + Bachelor diploma + None-Not selected	None	+ Environment related professional experience of the founder (5-10 years) + Average number of employees*: 11,688

“+” Represents a “Yes” or “selected” in the case of a multiple choice question

“-” Represents a “No” or “not selected” in the case of a multiple choice question.

None: The variables are not statistically significant.

* Corresponds to the year 2018 expressed in Full-Time Equivalent (FTE)

Class 2: Necessity entrepreneurs without environmental concerns

This class represents the smallest part of the sample (6.25%). The environmental aspect is not a major concern in this category of start-up, which is evident in the fact that they do not set environmental objectives for their products. They integrate the environmental aspect into their activity in a haphazard manner. The start-ups of this class tend to have no co-founders and the entrepreneur was often a job-seeker before creating the company. In the literature on entrepreneurship they are known as push entrepreneurs (Amit and Muller, 1995); they engage in an entrepreneurial activity because of lower opportunity costs (the individual is in a bad position in the labour market) (Oxenfeldt, 1943). Their goal is to earn enough money to make a living and they do not live to grow wealth (Choi and Gray, 2008). By contrast, “pull” entrepreneurs are those who start a business to exploit an attractive idea.

These start-ups have difficulties accessing funding and grants. They have very little access to external knowledge due to the lack of cooperation and exchange of ideas through meetings. This class shows great similarities with the ad hoc “enviropreneur” (Taylor and Walley, 2004) and with the unintentionally green start-up (Bergset and Fichter, 2015).

Class 3: Entrepreneurs with ecological awareness

This class represents 26.56% of the companies in the sample. These start-ups do not raise funds. This can be explained by the low interest of investors in this type of start-up or by the desire to keep full power over the decision-making process and avoid the risk of deviating from environmental objectives. They also do not have access to grants. The entrepreneurs created these start-ups because they were convinced of the need to provide solutions to environmental problems and of the notion that the challenges could be met through the efforts of all. Thus, they are making their contribution by developing an eco-innovative project. Their main objective is not profit; indeed the turnover is lower than 100,000 €. Their eco-innovation is an improvement of existing products (incremental eco-innovation). The environmental aspect is introduced in the product or service in the development phase; in fact, these companies have no R&D activity either internally or externally. They do not benefit from external knowledge because their networks and partners are limited.

The environmental orientation is stimulated by an internal factor based on the will of the founder and his team. The variable³³ “funded by sustainable investors”³⁴ is not significant. However, this can be explained by the small share (1.6%) of companies financed by sustainable investors in our sample. These start-ups have not selected “no incentive to environmental policy” and their managers

³³ Table 6 reports only the significant results, the detailed results are available upon request.

³⁴ Sustainable investors are investors who direct their investment capital towards firms that have an environmental and social impact.

tend to have a bachelor's degree. This class has features that are close to the ethical maverick (Taylor and Walley, 2004) and the alternative start-up (Bergset and Fichter, 2015).

Class 4: Market-driven opportunist entrepreneurs without environmental concerns

This class represents 25% of the start-ups in the sample. These start-ups were created following the discovery of market niches related to an increasingly high demand for environmentally-friendly products or services. Competition is less pronounced in these niches which are weakly occupied by large groups. The environmental aspect is introduced because it allows the company to exist and to make profits; they rarely carry out an environmental assessment of their products. They have weak access to funds and grants, as is the case for the class 2 start-ups (necessity entrepreneurs without environmental concerns). Investors have little interest in this category of start-up. They do not benefit from external knowledge due to the small number of their partners and to the non-participation in the exchange of ideas on environmental aspects through meetings. This class is comparable to the innovative opportunist (Taylor and Walley, 2004) and to the “ecopreneurial” start-up (Bergset and Fichter, 2015).

Class 5: Opportunist leaders³⁵

This class represents 25% of the sample. The start-up is created following the emergence of an idea which is conceived from the start in order to reduce or limit environmental impacts (frontstage eco-innovation). A research and development activity is carried out internally in order to implement the idea. These start-ups develop eco-innovative solutions for their activity and for industries that apply for eco-innovations allowing them to achieve cost savings. These are the most advanced start-ups in terms of integrating the environment into their activity. Their activity is organized through an environmental management system, they are therefore concerned with the image they project. The analysis of environmental impacts is a priority for their projects, with a desire to offer completely eco-designed products.

They are strongly committed to partnership and have an extended network, made up of other companies in their sector of activity, suppliers, consultants and private laboratories. They are generally created by entrepreneurs with professional experience related to the environment who have therefore been able to develop their network and know-how. These are projects that have also been supported by applied academic research. The main field of their intervention is the reduction of greenhouse gas emissions.

³⁵ This class shows similarities with that of Taylor and Walley (2004), but with the major difference that in our case these entrepreneurs do not have a personal environmental conviction.

These start-ups have strong development potential and a promising future. They manage to attract funding from private investors, especially during the development phase. They also manage to obtain subsidies, in particular from local authorities. Start-up companies that make up this class tend to have a medium to large salaried workforce, and the founder usually has 5 to 10 years of corporate experience related to the environment. This class shows similarities with the visionary champion (Taylor and Walley, 2004) and the visionary start-up (Bergset and Fichter, 2015).

2.5 Discussion and conclusions

This paper makes a contribution to the literature on sustainable entrepreneurship by focusing on the factors that stimulate start-ups to undertake eco-innovation. Firstly, we made a comparison between eco-innovators and non-eco-innovators according to two themes: human capital and environmental policy. The results show that eco-innovative start-ups differ in the skills acquired by the entrepreneur, in particular through environment-related studies and environment-related professional experience. The existence of “command and control” environmental instruments such as standards and prohibitions distinguish eco-innovators from non-eco-innovators. However, “economic instruments” such as environmental taxes do not separate the two groups of start-ups. Furthermore, the presence of a CSR policy (whether formalized or not) is an important differentiating factor. Secondly, we propose a typology of eco-innovative start-ups based on internal factors and external factors related to the environment in which the start-up operates (such as external knowledge). Due to the diversity of start-ups, we include internal factors that can play a key role, in this case such as access to funding, the entrepreneur’s human capital profile, and the environmental orientation. Start-ups are often combined with existing firms in studies on SMEs; however, these firms have specific features which make them adopt a different attitude towards eco-innovation. In this paper, we try to address the shortcomings observed in the literature by focusing on nascent start-ups. The typology is used to examine the distinctive characteristics of eco-innovators. It also allows us to distinguish between eco-innovators by considering economic, social and environmental motivation.

We have identified five categories of eco-innovative start-ups. Some of these categories have been mentioned in previous theoretical studies by Taylor and Walley (2004) and Bergset and Fichter (2015). The special feature of the necessity entrepreneurs without environmental concerns is their haphazard engagement in environmental activity. Entrepreneurs with ecological awareness are characterized by the entrepreneur’s strong environmental values. The main goal of the market-driven opportunist without environmental concerns is to make profits by exploiting environmental opportunities. Opportunist leaders display the highest environmental orientation, analysing the environmental impacts of products and implementing an Environmental Management System (EMS). They try to strike a balance between environmental goals and economic goals related to financial

performance, and have a proactive attitude; they go beyond the environmental constraints imposed from without.

The detailed examination of these classes shows that firms that develop radical eco-innovations and frontstage eco-innovations are those that are driven by economic performance, have access to funding or subsidies, have access to external knowledge, report a high level of environmental orientation, and are led by entrepreneurs who have acquired professional experience (opportunistic leaders, senior entrepreneurs with environmental concerns). On the other hand, start-ups that develop incremental eco-innovations are characterised by a low level of external knowledge and a lack of access to funding (entrepreneurs with ecological awareness). Radical sustainable innovation is a long-term investment (Bocken, 2015; Freimann et al., 2012) and constitutes a high risk, whereas investors expect to obtain their profits after a short period of time, which makes access to funds challenging (Bergset and Fichter, 2015). In relation to this analytical framework, we have shown empirically that different types of eco-innovative start-ups do not have the same difficulties in accessing funds, as has been assumed by Bergset and Fichter (2015). The category of start-ups that manage to attract investors is the opportunistic leaders, and this may be due to three main reasons. The innovations are radical; they are therefore attractive prospects for the investors who agree to fund them. Moreover, these companies are founded by older entrepreneurs with professional experience which has allowed them to develop their professional network. In addition, these start-ups have an economic motivation; they are therefore funded by conventional investors. Entrepreneurs with ecological awareness do not raise funds and have not obtained grants. This can be explained by two factors. They are selective in the choice of investors because they worry about the firm's objectives potentially being redirected, and they are therefore seeking investors that share the same sustainable values (Bocken, 2015; Choi and Gray, 2008). A second possible reason is that these firms may not strive to grow; their only desire is to meet their needs by exercising a profession consistent with their values.

Necessity entrepreneurs without environmental concerns do not have access to funds. This may be due to their lack of experience and lack of prior knowledge related to the environment. This leads to the exploitation of less profitable opportunities (Block and Wagner, 2010). Opportunistic leaders is the category of start-ups with the most successful cooperation network (cooperation with other companies, suppliers, universities, etc.). These start-ups display the highest environmental orientation; in fact, they set environmental objectives for their products and integrate the environmental aspect from the initial phase of the innovation process (frontstage eco-innovation). For this reason, external knowledge plays a crucial role for these firms. The establishment of this network is enabled, among other factors, by the professional experience related to the environment acquired by the entrepreneur. By contrast, cooperation plays a limited role in the case of the other classes.

These results are consistent with those obtained by Doloreux and Kraft (2019) which confirm that companies with a high eco-innovation intensity—namely fully-integrated eco-innovators³⁶—differ in the exploitation of external knowledge; in fact, they have a larger network.

Environmental regulation seems to have a limited role in the differentiation between the categories of eco-innovators, except in relation to the grants which are significant for two classes: opportunist leaders and senior entrepreneurs with environmental concerns. These results are consistent with those of Triguero et al. (2016) who find that environmental policy has no effect on the intensity of eco-innovation.

At European and French level, environmental policies are proposed to encourage companies' environmental practices. In this respect, it is crucial to understand the distinctiveness of eco-innovators versus non-eco-innovators, and to examine the different typologies of eco-innovators. Hence, this study has important implications for policy-makers.

Environmental policy in European countries is based on national objectives and only a few measures concern specific sectors or companies (Marin et al., 2015). It is mainly based on the traditional instruments of “command and control” and “economic instruments”; these instruments are insufficient. In fact, our results show that the effect of “economic instruments” is not significant.

The discriminant analysis on the human capital theme shows that environment-related education as well as environment-related professional experience differentiate eco-innovators from non-eco-innovators. Therefore, public policies should not focus solely on regulatory instruments but must also rely on other areas of application, including education. We are already seeing initiatives emerging to train young people for the professions of tomorrow—for example, the “campus transition” universities and “ecological transition schools”. These schools have the ambition to think of new economic models, and new ways of producing, consuming, and managing resources. Therefore, it is necessary to strengthen and support these emerging initiatives. One of the aims of the programme “Plan d'investissement dans les compétences” of the period 2018–2022 is to contribute to ensuring the workforce is qualified to respond to the changing skills demanded by ecological transition. However, we believe that this action is marginal and should be scaled up.

It has become clear from the taxonomic analysis that eco-innovators do not have a homogeneous profile. Indeed, there is a diversity of profiles among eco-innovators. Therefore, the

³⁶ They measure the eco-innovation intensity by the types of integrated eco-innovation. Fully integrated eco-innovators are start-ups that practise different types of eco-innovations.

main implication is that the implementation of public policy must take into account the diversity of eco-innovators' profiles.

Senior entrepreneurs with environmental concerns have carried out an activity which has enabled them to build up the funds to start a business. In addition, they have extensive professional experience and have been able to build up a professional network. This allows society to benefit from their experience. At the same time, this activity allows them to benefit from additional income to their retirement pensions. In an economy characterized by an aging population, this phenomenon could be replicated widely if it is properly stimulated and supported, and it could contribute to achieving the objectives of sustainable development. We highlighted that seniors create their business with co-founders. This promotes complementarity between the experience and the availability of resources of seniors with the technical skills of young people in new technologies. Efforts to bring these two parties together are necessary. Therefore, it is important to encourage intergenerational co-entrepreneurship, in particular by setting up associations and private and public support structures that will be able to match up these two parties, or by creating networking platforms. This could create jobs and make it possible to sustain the financing of social protection whilst reducing the environmental impact.

Entrepreneurs with ecological awareness can play an important role in sustainable development. It is necessary to support them through funding. Sustainable investors share the same environmental values as entrepreneurs with ecological awareness. However, the variable "funded by sustainable investors" introduced in the taxonomic analysis is not significant. In our case, this may be due to the small number of companies funded through this mode of finance. Sustainable investment is emerging: the number of sustainable investors is increasing but remains very low. We consider it a suitable financing method for firms with an ecological awareness based on their common values. For sustainable investors and start-ups with an ecological awareness to find their way into the market, the network needs to be developed and organized in a formal way and the start-ups and investors need to show a clear signal of their "sustainable" character (Demirel et al., 2019). Because of this information asymmetry, it is necessary to facilitate the right match between sustainable investors and entrepreneurs with an ecological awareness by setting up an impact measurement such as an "impact factor" recognized by the state to assess and evaluate the "sustainability" of projects, and it is also necessary to promote "green" investment platforms.

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Partie A: Informations générales sur l'entreprise

A1. Nom de l'entreprise

A2. Année de création

A3. Destination des produits de l'entreprise

Marché local ou régional

Marché national

Marché européen

Marché international

A4. Parmi les instruments de politique environnementale suivants, indiquer ceux auxquels vous êtes soumis

Normes, autorisations, interdictions imposées par la réglementation environnementale

Taxes sur les inputs (Energie)

Taxes sur les émissions polluantes

Aucun

Autre

Autre

A5. *La RSE (Responsabilité Sociale des Entreprises) regroupe l'ensemble des pratiques mises en place par les entreprises dans le but de respecter les principes du développement durable, c'est-à-dire être économiquement viable, avoir un impact positif sur la société mais aussi mieux respecter l'environnement.*

Existe-t-il une démarche RSE au sein de votre entreprise ?

Oui

Non



A6. En moyenne, sur les cinq dernières années, le chiffre d'affaires de votre entreprise se situe entre:

L'entreprise n'a pas encore commencé à commercialiser ses produits

[0;100 000]

[100 001; 500 000]

[500 001; 1000 000]

Plus d'un million d'euros

A7. Effectif salarial (en Équivalent Temps Plein) de l'entreprise sur les trois dernières années.

2018

2017

2016

Partie B: Profil de l'entrepreneur

Cette partie concerne uniquement l'entrepreneur

B1. Sexe

Féminin

Masculin

B2. Dans quelle classe d'âge vous situez-vous ?

18-25 ans

26-35 ans

36-44 ans

45- 54 ans

55 ans et plus



B3. Quel est votre plus haut diplôme obtenu ?

- Doctorat (Bac +8)
- Master, Ingénieur (Bac +5)
- Licence (Bac +3)
- Bac général ou professionnel
- BEP, CAP
- Sans diplôme
- Autre

Autre

B4. Avez-vous obtenu un diplôme en lien avec l'environnement ?

Oui

Non

B5. Quelle était votre situation professionnelle avant la création de votre entreprise actuelle ?

Salarié

Demandeur d'emploi

Étudiant

Dirigeant dans une autre entreprise

Autre

Autre

B6. Si vous étiez salarié ou dirigeant dans une autre entreprise, l'expérience acquise a-t-elle un lien avec l'environnement ?

Oui

Non



B7. Combien d'années cette expérience en entreprise a-t-elle duré ?

Moins d'un an

Entre un et cinq ans

Entre cinq et dix ans

Plus de dix ans

Autre

Autre

B8. Existe-il un autre cofondateur de l'entreprise?

Oui

Non

B9. Indiquer le nombre de cofondateurs

Partie C: Activités d'innovations

Les deux parties qui suivent concernent l'innovation Non environnementale et l'innovation environnementale.

Veillez lire les définitions suivantes avant de répondre aux questions :

« L'innovation est la mise au point des produits, des procédés ou des associations de produits et procédés technologiquement nouveaux ou notablement améliorés ... ». (Manuel d'Oslo, 2005)

« L'innovation environnementale est la production, l'assimilation ou l'exploitation d'un produit, d'un procédé de production, d'un service, ou d'un outil managérial qui est nouveau pour l'organisation qui le développe ou l'adopte, et qui conduit à la réduction des risques environnementaux, de la pollution, et des autres impacts négatifs de l'utilisation de ressources (y compris de l'énergie) ... ». (Rapport de l'OCDE "mesurer l'éco-innovation", 2008)

C1. Veuillez indiquer la ou les innovations qui vous concernent :

Innovation Non environnementale

Innovation environnementale

Les deux types d'innovations (environnementale et Non environnementale)

L'entreprise n'est pas concernée par l'activité d'innovation



Partie D: Innovation Non environnementale

D1. Au cours des cinq dernières années, votre entreprise a-t-elle introduit ou développé une ou plusieurs innovation(s) ?

Oui

Non

D2. Au cours des cinq dernières années, les innovations introduites étaient-elles :

Entièrement nouvelles au marché (Innovation radicale)

Une amélioration des produits , services, procédés,...existants sur le marché (Innovation incrémentale)

L 'adoption d'une nouvelle innovation par l'entreprise

Autre

Autre

D3. À quelle fréquence avez-vous adopté les pratiques et mécanismes suivants au cours de cette phase initiale d'innovation ?

1- Benchmarking: processus continu d'évaluation des produits, des services et des méthodes par rapport à ceux des concurrents.

2- Brainstorming: recenser le maximum d'idées, d'information ou de solutions

3- Feuille de route technologique: document qui décrit le plan pour atteindre des objectifs à court et à long terme grâce à l'utilisation de solutions technologiques.

Jamais Rarement Parfois Souvent

1- Benchmarking

2- Brainstorming

3- Technology roadmap (Feuille de route technologique)

4- Analyse ou étude de marché

D4. Pour quel(s) motif(s) votre entreprise a-t-elle introduit ou développé une innovation ?

Réduire les coûts

Gagner des parts de marché (compétitivité)



Améliorer l'image de l'entreprise

Etre en phase avec les exigences règlementaires environnementales

Autre

Autre

D5. Au cours des cinq dernières années, pour vos activités d'innovations, avez-vous effectué des levées de fonds ?

Oui

Non

D6. Indiquer la ou les source(s) de financement.

Financements par un apport personnel, des amis ou la famille

Investisseurs privés ou fonds de capital-risque

Crowdfunding (financement participatif)

Business Angel (investisseur providentiel)

Fonds de capital développement

Autre

Autre

D7. Votre entreprise a-t-elle bénéficié, au cours des cinq dernières années, de subventions liées à l'activité d'innovation ?

Oui

Non

D8. Indiquer leur(s) origine(s).

Collectivités locales (Région, départements, communes)

Organismes nationaux (Ministères, ANR...)

Union Européenne (FEDER, FSE ...)



Autre



Autre

D9. Votre entreprise réalise-t-elle des activités de Recherche et Développement (R&D) ?

Oui, en interne

Oui, en externe (par d'autres entreprises, organismes de recherche publics ou privés)

Aucune activité de R&D

D10. Votre entreprise a-t-elle coopéré avec d'autres entreprises ou organismes pour ses activités d'innovations ?

Oui

Non

D11. Indiquer les types de partenaire(s) et la dimension géographique.

Dans les cases commentaires, Mettez les lettres "r" pour un partenariat dans la même région administrative et "a" pour d'autres régions françaises ou internationales

Concurrents ou autres entreprises de votre secteur d'activité



Commentaire

Autres entreprises de votre groupe ou de votre réseau d'enseigne



Commentaire

Consultants, laboratoires commerciaux ou privés



Commentaire



Fournisseurs d'équipements, matériels, composants, logiciels

Commentaire

Organismes publics de R&D ou instituts privés à but non lucratif

Commentaire

Universités ou établissements d'enseignement supérieur

Commentaire

Autre

Autre

D12. Votre entreprise a-t-elle déposé, ces cinq dernières années, un brevet ?

Oui

Non

D13. Les salariés bénéficient-ils de formations en interne ou externe à l'entreprise ?

Oui

Non

D14. Les salariés de l'entreprise participent-ils à des échanges d'idées sur les thématiques en lien avec les activités d'innovation de l'entreprise (ateliers, conférences, ou séminaires) ?

Oui

Non



Partie E: Innovation environnementale

E1. Au cours des cinq dernières années, votre entreprise a-t-elle introduit ou développé une ou plusieurs innovation(s) environnementale(s) ?

Oui

Non

E2. Au cours des cinq dernières années, parmi les innovations environnementales suivantes, indiquer celle(s) que vous avez introduite(s) ou développée(s).

Économie d'énergie (Isolation, solutions d'économie en matière d'éclairage, de climatisation ou de chauffage,...)

Technologies d'énergies renouvelables (Eolienne, solaire, biomasse, ...)

Recyclage et/ou diminution des déchets

Technologies visant à réduire les émissions polluantes (CO2, NO2, ...)

Autre

Autre

E3. Au cours des cinq dernières années, les innovations environnementales introduites étaient-elles :

Entièrement nouvelles au marché (Innovation radicale)

Une amélioration des produits , services, procédés,...existants sur le marché (Innovation incrémentale)

L' adoption d'une nouvelle innovation par l'entreprise

Autre

Autre



E4. Innovation environnementale « Front stage » est la phase initiale du processus d'innovation. Elle est caractérisée par l'identification de l'opportunité et la sélection de l'idée.

À quelle fréquence avez-vous adopté les pratiques et mécanismes suivants au cours de cette phase initiale d'innovation environnementale ?

Définitions de concepts

1- *Eco-conception: intégrer la protection de l'environnement dès la conception des biens ou services. Elle a pour objectif de réduire les impacts environnementaux des produits tout au long de leur cycle de vie : extraction des matières premières, production, distribution, utilisation et fin de vie).*

2- *Benchmarking environnemental: évaluer la performance environnementale de l'entreprise et identifier des pratiques susceptibles de l'améliorer)*

3- *Eco-Brainstorming :recenser le maximum d'idées, d'information ou de solutions en mettant l'accent sur l'aspect environnemental)*

	Jamais	Rarement	Parfois	Souvent
1- Eco-conception	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2- Benchmarking environnemental	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3- Eco-Brainstorming	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4- Analyser les impacts environnementaux des produits	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5- Fixer des objectifs environnementaux aux produits	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

E5. À quelle étape du processus d'innovation avez-vous introduit l'aspect environnemental?

Phase initiale du processus d'innovation (identification de l'opportunité et sélection de l'idée)

Phase de développement (exécution de l'idée via un processus de test, développement et mise en œuvre)

E6. Parmi les méthodes de management environnemental suivantes, indiquer celle(s) que vous avez adoptée (s) ?

Certifications (ISO 5001, ISO 14001, ISO 16000, ISO14064)

Système de management et d'audit environnemental

Fixer des objectifs environnementaux pour vos produits

Méthodes permettant d'être informé des nouvelles exigences réglementaires environnementales

Analyser les impacts environnementaux de vos produits

Non concerné



Autre



Autre

E7. Pour quel(s) motif(s) votre entreprise a-t-elle introduit ou développé une innovation environnementale ?

Aides publiques en lien avec l'environnement

Réduire les coûts

Gagner des parts de marché (compétitivité)

Améliorer l'image de l'entreprise

Faire face à une demande de plus en plus importante envers les produits respectueux de l'environnement

Etre en phase avec les exigences réglementaires environnementales

Conscience écologique

Autre

Autre

E8. Au cours des cinq dernières années, pour vos activités d'innovations environnementales, avez-vous effectué des levées de fonds ?

Oui

Non

E9. Indiquer la ou les source(s) de financement

Financements par un apport personnel, des amis ou de la famille

Investisseurs privés ou fonds de capital-risque

Crowdfunding (financement participatif)

Business Angel



Fonds de capital développement

Eco –investisseurs

Autre

Autre

E10. Votre entreprise a-t-elle bénéficié, au cours des cinq dernières années, des subventions liées à l'activité d'innovation environnementale ?

Oui

Non

E11. Indiquer leur(s) origine(s)

Collectivités locales (Région, départements, communes)

Organismes nationaux (Ministères, ANR...)

Union Européenne (FEDER, FSE ...)

Autre

Autre

E12. Votre entreprise réalise-t-elle des activités de Recherche et Développement (R&D) ?

Oui, en interne

Oui, en externe (par d'autres entreprises, organismes de recherches publics ou privés)

Aucune activité de R&D

Autre

Autre



E13. Votre entreprise a-t-elle coopéré avec d'autres entreprises ou organismes pour ses activités d'innovations environnementales ?

Oui

Non

E14. Indiquer les types de partenaire(s) et la dimension géographique.

Dans les cases commentaires, Mettez les lettres "r" pour un partenariat dans la même région administrative et "a" pour d'autres régions françaises ou internationales

Concurrents ou autres entreprises de votre secteur d'activité

Commentaire

Autres entreprises de votre groupe ou de votre réseau d'enseigne

Commentaire

Consultants, laboratoires commerciaux ou privés

Commentaire

Fournisseurs d'équipements, matériels, composants, logiciels

Commentaire

Organismes publics de R&D ou instituts privés à but non lucratif

Commentaire

Universités ou établissements d'enseignement supérieur

Commentaire



Autre



Autre

E15. Votre entreprise a-t-elle déposé, ces cinq dernières années, un brevet en lien avec l'innovation environnementale ?

Oui

Non

E16. Les salariés bénéficient-ils de formations en interne ou externe à l'entreprise en lien avec l'environnement ?

Oui

Non

E17. Les salariés de l'entreprise participent-ils à des échanges d'idées sur les thématiques environnementales (ateliers, conférences, ou séminaires) ?

Oui

Non

Chapitre 3

Eco-innovative firm location: What is the role of knowledge spillovers?³⁷

3.1 Introduction

Since the 1990s, environmental issues have become a major concern for policy makers. Faced with the threat of global warming, it has been essential to reduce energy consumption, limit the use of fossil fuels, and promote the development of low-carbon energies. This requires a radical technological transformation of the global energy system, and the rapid establishment of policies to encourage the development of innovation with the aim of reducing environmental impact and promoting more efficient use of natural resources.

The implementation of national and sectoral policies promoting eco-innovation has become a key issue for Europe's future competitiveness. With the Act of 17 August 2015 on Energy Transition for Green growth, France has displayed its ambition to be an exemplary nation in terms of reducing its greenhouse gas emissions, diversifying its energy system and increasing the deployment of renewable energy sources. The Act sets out many quantitative goals, in particular, a commitment to reduce greenhouse gas emissions by 40% by 2030, compared to 1990 levels, and divide it by four by 2050 as well as to increase the share of renewables in final energy consumption up to 32% by 2030. And it is in this context that the creation of innovative firms highly specialised in environmental technologies may have a key role in the transition process to a sustainable economy (OECD 2011, 2016; EC 2012; French Government 2017). In this regard, France is responsible for a specific program that supports the creation of eco-innovative firms with a special focus on the development of innovation (ADEME 2018). The capacity of regions to develop new green technologies is also one of the bases of the Smart Specialisation Strategies (RIS3) proposed by European Commission over the

³⁷ This chapter is a joint work with E. Coll-Martinez and P. Renou Maissant, it is currently under review at the Annals of Regional Science. It has also been presented at several conferences including ERSA and AFSE.

last years to ensure (EC 2012). It seems clear, then, that the development of policies encouraging the creation of environmental technologies and their sustainable application in firms' activity may have many implications for the transition to a greener and sustainable economy of regions, in this case, for French *départements*.

Despite the increasing interest in the development of eco-innovation, the number of contributions analysing the regional factors that may explain the location of eco-innovative activities is still limited (see, for instance, Barbieri et al. 2016 or Dechezleprêtre and Sato 2017). To do so it is important to consider the nature behind regional knowledge bases taking into account their actual capacity to generate green innovations. And this requires the use of alternative approaches to capture the distinctive traits of environmental innovations (Barbieri et al. 2020) and a thorough investigation in the actual role of related and unrelated diversification in regions as Boschma (2016) suggested as one of the main challenges in the literature.

Therefore, with this paper we aim to contribute to the literature on the location determinants of eco-innovative firms and shed light on the relationship between knowledge spillovers and the creation of new innovative firms highly specialised in the environmental field. Concretely, we address the following research questions. First, does the accumulated knowledge coming from environmental technologies matters more than knowledge coming from non-environmental technologies in the creation of eco-innovative firms? Second, does the creation eco-innovative firms benefit more from related or from unrelated knowledge variety (in terms of the recombination of technologies that make up environmental inventions)? And third, is the creation of eco-innovative firms positively influenced by the local knowledge base and firm creation in neighbouring regions? The answers to these questions are useful for the development of regional policies to encourage the spatial concentration of environmental knowledge creation that, to some extent, may increase regional disparities in terms of environmental performance and knowledge creation or, on the contrary, reduce them. Moreover, the understanding of the dynamics of the eco-innovative firms' entry can provide useful information on how to boost local development through their direct and indirect spatial spillovers arising from the formation of eco-innovative activities in neighbouring regions. Finally, they would provide valuable ex-ante evidence of the Smart Specialisation Strategies (RIS3) proposed by European Commission to ensure the sustainable regional competitiveness in European Regions (EC 2012; Montresor and Quatraro 2020).

Only two comparable works have analysed these issues: Corradini (2019) and Colombelli and Quatraro (2019). As far as we know, Corradini (2019) was the first paper to analyse the location determinants of new green technology-based firms across European regions by using the characteristics of patent applications to define them as eco-innovative. Their results show that the

geographical distribution of green technology entry across European regions is not evenly distributed, giving evidence of the significant role played by the characteristics of the regional innovation system. Regarding Colombelli and Quatraro (2019), they provide evidence of the effects of the technological composition of local stocks of knowledge in the creation of green start-ups across Italian NUTS3 regions.

Against this background, the present paper departs from previous contributions in several ways. First, we provide evidence of the extent to which the balance between the accumulated local stock of environmental and non-environmental inventions matters for the creation of eco-innovative firm. Second, we propose a set of knowledge indicators capturing the degree of variety defining the local knowledge base focusing on technological recombinations of environmental-based patents. By doing so, we are able to disentangle the degree of diversity of the local knowledge base in terms of the recombination of environmental and non-environmental technologies as well as the recombination of the diverse environmental technological classes making up environmental patents that cannot be captured when using the traditional knowledge variety indicators that take into account all kinds of patents. Third, we introduce spatial autocorrelation techniques to identify spatial spillovers associated with the accumulated endowments of knowledge in the environmental technologies and eco-innovative firms' creation. Finally, we provide evidence on the location determinants of new eco-innovative firms' entry in the case of France, which is subject of increasing interest.

By using firm-level microdata on the location of new firms from DIANE Mercantil Register (Bureau van Dijk) and patent information from the OECD REGPAT (2018) database, we propose a set of knowledge indicators capturing the recombination process leading to the generation of environmental inventions and their impact on the propensity for the creation of environmental technology-based firms in French *départements* over the period 2003-2013. The main results show that the combination of broad and diverse technological knowledge for environmental technologies and political support in terms of investments for the protection of the environment are the main factors explaining the location of eco-innovative firms. Indeed, by applying spatial econometrics we found that there is a clear spatial dependence on their creation, while the impact of knowledge composition is quite local: results that are in line with the RIS3 policies proposed by the European Commission over the recent years (EC 2012).

The paper is organized as follows. Section 2 reviews previous contributions analysing the location determinants of eco-innovative firms and the role of knowledge spillovers in this process. In Section 3, we describe the data set and the variables used. In Section 4, we present the methodology and the econometric specification. Section 5 reports the main results. Finally, Section 6 offers some concluding remarks and policy implications.

3.2 Local knowledge composition and eco-innovative firm creation

Eco-innovation is a complex concept, it is important to delineate its boundaries. In this paper, we adopt the definition of the European Commission report: “Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives” (Kemp and Pearson 2007). This definition includes all innovations that can alleviate the environmental burden of economic activities regardless of the motivation behind their development or adoption. Thus, it includes innovations that are new to the firm or to the market, it also considers the innovations that contribute unintentionally to protecting the environment. Yet when considering this broad definition of eco-innovation, it is hard to find an indicator that is suitable for measuring it. As with classical innovations, patents are among the most widely used indicators for measuring eco-innovation (see among others, Colombelli et al., 2019; Costantini et al., 2017; Faria and Andersen, 2017; Marin, 2014). However, the use of this indicator limits the definition of eco-innovation. In fact, patents generally reflect technological eco-innovations that are new to the market.

The interest in eco-innovation stems from its environmental and economic benefits to society (Horbach 2008). The potential benefits of eco-innovations can easily spill over into society through the creation of new firms specialised in environmental technologies. In this regard, there is a wide consensus on the key role of start-ups in generating technological innovations as well as in its transmission process over the economy (Acs and Audretsch 1987; Rogers 2004; Audretsch et al. 2006; European Commission 2011; OECD 2016). In fact, environmental innovations may lead to radical change because of the absence of established environmental best practice and technological trajectories (Barbieri et al. 2020). For this reason, understanding the factors that may incentivise the creation of eco-innovative firms is becoming more and more relevant to provide evidence on the regional characteristics that may boost the generation and diffusion of environmental inventions. However, there are not many contributions to the literature that analyse location determinants of eco-innovative firms.

Most literature related to this field is based on the evolutionary economic geography literature (Boschma and Martin 2010; Boschma and Frenken 2011) and the theories of knowledge creation and the role of knowledge spillovers in new firm creation (Acs et al. 2009, 2013). According to this literature, one of the main factors explaining the creation of new innovative firms is the local available stock of knowledge (Acs et al. 2009; Audretsch et al. 2015). In the case of environmental technologies, there is already (mixed) evidence showing that the availability of local knowledge is expected to have

an important role on the creation of eco-innovative firms. Still, the benefits stemming from the available accumulated local knowledge stock may differ according to the dominant technologies being developed in the region. In this direction, some authors found that eco-innovative start-ups benefit more from knowledge spillovers coming from ‘clean’ technologies than from ‘dirty’ technologies (Colombelli and Quatraro 2019). On the other hand, Quatraro and Scandura (2019) consider that the specialisation of green technological innovations depends substantially more upon the stock of non-green technologies; while others found that both environmental and non-environmental knowledge are positively associated with the emergence of specialisation in environmental technologies (Montresor and Quatraro 2020). Despite this mixed evidence, we may consider that both kinds of knowledge should be relevant to the formation of eco-innovative firms due to the wider scope of application of environmental technologies with regards to other technologies (Dechezleprêtre et al. 2013).

Based on the above premises, we can formulate the following research question:

RQ1: *Does the creation of eco-innovative firms benefit more from the accumulated knowledge coming from environmental technologies or the other way around, that is, the accumulated knowledge coming from non-environmental technologies.*

Besides the available local accumulated stock of knowledge, some authors argue that the domains over which local knowledge spans are also important when it comes to explaining the location patterns of (eco)-innovative start-ups (Colombelli and Quatraro 2018). In fact, technological progress is explained within recent evolutionary economics literature by a new theory of innovation namely the recombinant innovation. This approach suggests that new ideas are generated through the recombination of existing ideas (Castaldi et al., 2015; van den Bergh, 2008; Weitzman, 1998). It follows from the notion of recombinant innovation that the development of new technologies, and environmental technologies too, is a place- and path-dependent process, which benefits from the variety of local available knowledge by recombining it in a new manner (Balland, 2016). In this regard, there is ample empirical confirmation for the fact that knowledge base dimensions such as variety and relatedness affect the knowledge recombination effectiveness and firm formation dynamics (Bae and Koo 2009; Colombelli 2016). Regional technological heterogeneity is characterized by the presence of actors with different technological competencies and then a broader set of combinatorial opportunities leading to the creation of new innovative firms (Castaldi et al., 2013; Corradini and De Propris, 2015). Even the complementarity degree of regional knowledge configuration is important, increasing similarity may lead to negative effects. Thus, an excessive level of relatedness is likely to engender technological lock-in (Boschma 2005; Colombelli and Quatraro 2013). The most favourable configuration for the emergence of knowledge-based entrepreneurship is characterized by high levels

of both relatedness and variety. In fact, a high degree of relatedness is associated with reduced knowledge asymmetries and uncertainty and an improvement in the entrepreneurial absorptive capacity; while a high degree of variety is associated to more technological opportunities (Colombelli and Quatraro 2018).

Among the few contributions analysing the impact of knowledge spillovers on the creation of eco-innovative firms, Colombelli and Quatraro (2019) and Corradini (2019) stand out. On the one hand, Corradini (2019) found an inverted-U relationship between regional technological relatedness and green technological entry. In this regard, technological activities related to environmental technologies available in regions trigger the development of green technologies. However, an excessive level of relatedness may have a negative effect by limiting the set of opportunities for recombinations with other technological domains, leading to a decrease of green technological entries. On the other hand, Colombelli and Quatraro (2019) pointed out the importance of technological variety for the generation in green innovative start-ups as well as the historical process of knowledge accumulation in which the combination of related and highly complementary technological fields is relevant for the effective exploitation of technological opportunities in the green domain.

In practical terms, different strategies can be followed by regions in order to foster eco-innovative firms' entry. Some regions could follow a strategy based on unrelated diversification by investing in technologies different from the pre-existing ones (e.g., the production of electric cars in absence of a consolidated experience in the automobile sector). Other regions may exploit and combine the existing non-environmental innovations with eco-innovations into new hybrid solutions (e.g., the hybrid car combining an internal combustion engine with an electric propulsion one and photovoltaic films combining thin layer technologies with solar technologies) (Zeppini and van den Bergh, 2011). These strategies are examples of the wider scope of application of environmental technologies due to their complexity and specific nature (Quatraro and Scandura 2019; Santoalha and Boschma 2019).

Therefore, understanding the specific recombination of the different technologies leading to environmental in at regional level is of vital importance for the set-up of regional policies to encourage the development of eco-innovative activities. Nevertheless, previous contributions were not able to capture the specific recombination of knowledge that makes up environmental technologies (e.g. Corradini 2019, Colombelli and Quatraro 2019). One exception is the work of Barbieri et al. (2020), although they do not analyse the location determinants of eco-innovative firms, their work confirms the additional complexity and novelty is not straightforward and requires alternative approaches to understand their knowledge sources, by assessing the impacts of inventive activities on subsequent technological developments, focusing, especially, on the spillover potential of green technologies .

So, this paper aims to fill this gap by examining the impact of the recombination of non-environmental and environmental technologies as well as the recombination of the diverse technological classes within green technologies on the creation of eco-innovative firms. This application is particularly relevant for the purposes of our paper since new environmental technologies rely more on the recombination of different pieces of knowledge that are often cognitively distant than non-environmental technologies do and they are also characterized by technological uncertainty that requires access to skills that cannot usually be found in the firm's knowledge domain (De Marchi, 2012; Barbieri et al. 2016; Orsatti et al. 2017; Fusillo 2019; Quatraro and Scandura 2019).

Considering all these facts, we can formulate the following research question:

RQ2. *To what extent does the creation of eco-innovative firms benefit more from related variety than from unrelated variety (in terms of environmental technologies), or from both?*

From a regional policy perspective, it is important to understand whether these knowledge spillover may have an impact beyond *départements* limits. In this regard, previous contributions from Colombelli and Quatraro (2019) and Corradini (2019) argue that spatial path dependence and regional dynamics are important for fostering eco-innovation; however, they do not account for the fact that the local environmental technological knowledge base generated in neighbouring regions may spill over into other regions and that eco-innovative firm creation may be clearly influenced by the development and creation of environmental technologies in neighbouring regions (Rennings and Rammer 2009; Horbach et al. 2013; Ghisetti et al. 2015).

Based on the above premises, we can formulate the following research questions:

RQ3. *Is there a contagious effect in the creation of eco-innovative firms between regions?*

RQ4. *Does the local environmental technological knowledge base may spill over into other regions?*

3.3 Empirical analysis

3.3.1 Data

To analyse the location determinants of eco-innovative firms, we make use of patent, firm-level data and regional economic statistics for the 96 metropolitan *départements* across France between 2003 and 2013. The *département* is an administrative division of France which is equivalent to NUTS3

regions.³⁸ Patent data are obtained from the OECD REGPAT (2018)³⁹ database, which derives from two complementary sources of data: the European Patent Office's (EPO) Worldwide Statistical Patent Database (PATSTAT) and the EPO's *epoline* Database.

The patent count is conducted using specific selection criteria. We selected the patents filed in the European Patent Office (EPO) by companies located in France. Applicant count rather than inventor count is used. The applicants are assigned to the *départements* according to their addresses. Analyses of the geography of knowledge spillovers using disaggregated patent data have mainly used an inventor-level analysis (see for instance, Henderson et al. 2005; Breschi and Lissoni 2009; or Colombelli and Quatraro 2018, among others). However, inventors' residential addresses may not represent the place where the invention occurred (Antonelli et al. 2010; Quatraro 2010; Inoue et al. 2019). Because of this, in the present paper we rely on applicants' addresses. Applicants' addresses may capture the regional capacity to foster technology-based firms' entry more accurately than inventors' address may do it.

Patents are attributed to technological fields according to the CPC classification. We consider the main CPC codes and all their sub-classes. It is worth noting that a search strategy based on CPC classification is an easier and more reliable way to select green patents (for more details, see Veeffkind et al., 2012). In fact, patents are assigned to technological fields using two main classifications: International Patent Classification (IPC) and the Cooperative Patent Classification (CPC). Until now, most studies have been based on the IPC code (Kruse, 2016; Marin, 2014). When using this method, one should look for green patents in different classes (Dechezlepretre et al., 2011; Johnstone et al., 2009). This data retrieval method carries two risks: selecting irrelevant patent applications and excluding relevant patent applications (Veeffkind et al., 2012). Since 2013, the EPO has completed the CPC classification which includes a classification, named the Y class, dedicated to applications related to green technologies. So, in this paper, are considered as environmental patents climate change mitigation technologies related to: buildings (Y02B), energy (Y02E), transportation (Y02T), the production of goods (Y02P), capture and storage of greenhouse gases (Y02C), information and communication (Y02D), water waste and treatment (Y02W). We also include technologies for the adaptation to climate change (Y02A) and smart grids (Y04S).

³⁸ NUTS means: Nomenclature of Territorial Units for Statistics. The European Commission divides its territory according to the classification established by Eurostat. It is based on national administrative units.

³⁹ Due to the data unavailability, in the REGPAT database, on the marketability of the patented objects and their economic value, we use the terms of invention and innovation interchangeably.

In order to find out the year in which the firm was founded, the patent data is merged with the DIANE database that contains financial information on firms in France. Due to the absence of a common identifier between the REGPAT database and the DIANE database, the name and the address of companies were used to merge these two datasets following the methodology used by Marin (2014). The OECD's Harmonization of Applicant Names (HAN) dataset is used to address the issue of name harmonization. The result of the firm matching was checked manually, on a case-by-case basis. Finally, the resulting database is completed by the information on local characteristics of French *départements* (96) taken from different sources such as INSEE, the French Government and Eurostat. A summary of definitions, sources and descriptive statistics can be found in Table 3.1.

3.3.2 Variables

Dependent variable

As the main aim of this paper is to understand the entry of innovative firms specialising in environmental technologies, we define eco-innovative firm entry as the entry of an innovative firm into the environmental technology industry. This approach is based on studies in evolutionary economics focusing on real technological firm entry rather than the traditional approach that identifies new firm creation through the date of incorporation of firms into the market (Malerba and Orsenigo 1999; Corradini and De Propris 2015; Corradini 2019).

To identify eco-innovative firms' entry, we follow the proposal of Corradini (2019) so as to retain only those firms that are highly specialised in eco-innovation. According to this schema, environment-based firm entries are those that have, over the period observed, at least 50% of their inventions classified as environmental technologies and that have applied for their first eco-patent within the first 5 years after their creation.

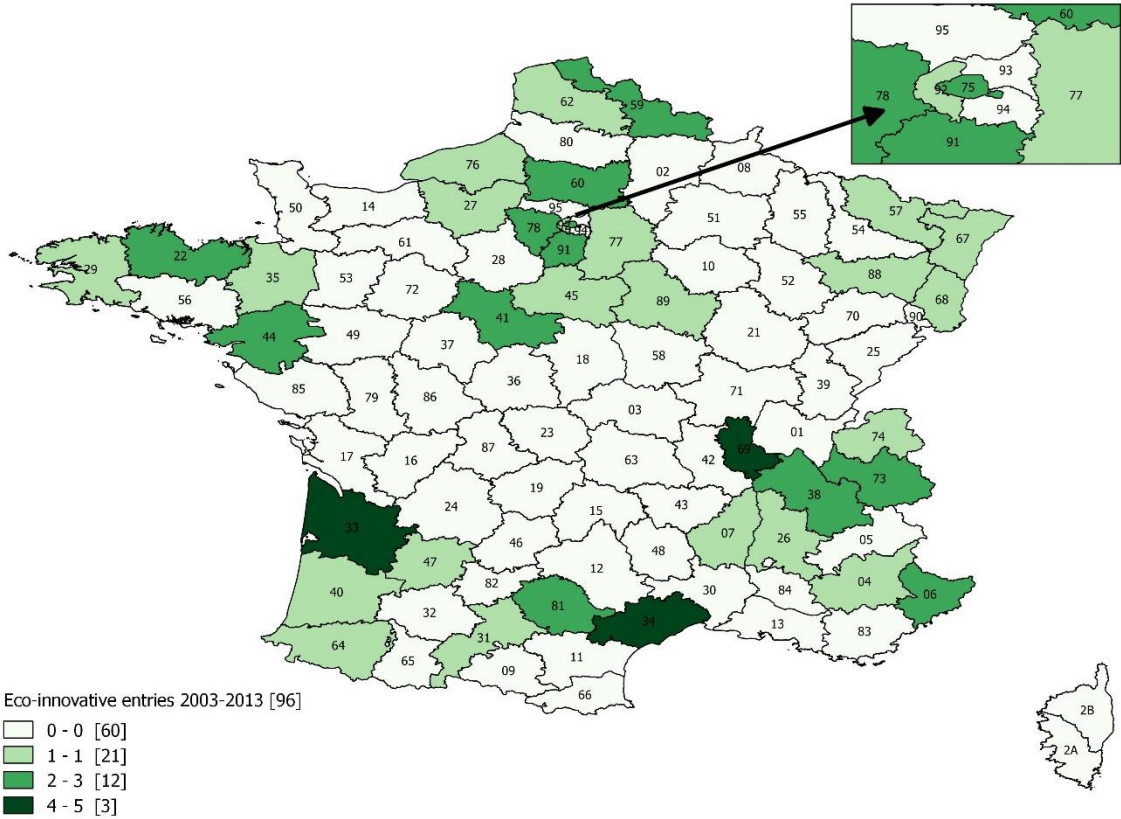
By retaining only firms that have been created no earlier than 5 years from the first patent application we are more certain to capture the entry of new firms since the date of the first patent and the date of the firm's creation may not coincide (Breschi et al. 2010). To identify the year of incorporation into the environmental technology-based industry, we consider the year in which they applied for an environmental-based patent for the first time.

The use of patents to define eco-innovative firm entry is important since it provides evidence on the subset of technology intensive firms eco-innovative firms as key agents to introduce radical

innovations on the economy favouring a more rapid transition to a sustainable economy (Nelson and Winter 1982; Klepper 1996; Storey and Tether 1998, Ejeremo and Xiao 2014; Corradini 2019).⁴⁰

Figure 3.1 shows the distribution of the number of eco-innovative firms’ entry across the 96 French *départements* between 2003 and 2013. What stands out from this figure is a non-homogenous spatial distribution of eco-innovative firms’ entry throughout French *départements*, as roughly 75% of innovative firms locate in and around Île-de-France and in the most populated *départements* such as Rhône (69) or Gironde (33). In fact, these are *départements* specialised in the chemical and pharmaceutical industries, among other industries. Thus, we guess that in such industries the incentives to develop environmental innovations are higher than in other regions due to the specific needs associated with these industries.

Figure 3.1 Geographical distribution of eco-innovative firm entries (2003-2013)



⁴⁰ By relying on patents data to capture eco-innovative firms’ entry we are not able to encompass the whole set of firms that innovate in the environmental domain since not all innovative firms may be able to apply for patents. Nevertheless, with this approach we can focus on highly technological-intensive firms operating in the environmental domain.

Table 3.1 Summary Statistics

Variable	Description	Source	Obs.	Mean	Std. Dev.	Min.	Max.
ECO_ENTRY	Eco-innovative entry	Own elaboration (DIANE & OECD REGPAT 2018)	1056	0.055	0.228	0.000	1.000
UNEMP	Unemployment Rate at 31st December (%)	Eurostat	1056	8.366	1.766	4.000	14.800
POP_DEN	Inhabitants per Km ²	Eurostat	1056	551.129	2420.114	14.600	21317.9
SCITECH	Share of persons with tertiary education and employed in Science and Technology.	Eurostat	1056	0.177	0.037	0.086	0.276
DIST_PARIS	Distance to Paris from the capital of the Department in minutes	Own elaboration	1056	4.395	2.751	0.000	15.580
ECO_INVEST	Total amount of investments for the protection of the environment (millions of euros)	INSEE - Antipol	1056	16.598	18.109	0.000	139.799
VOTE_ECO	Share of votes for the ecological party in the 2002, 2007 and 2012 French national elections (1 st round).	French Government – Ministère de l'Intérieur (data.gouv.fr)	1056	0.925	0.645	0.000	2.940
STOCK_ALL	Department-level stock of patents	Own elaboration (OECD REGPAT 2018)	1056	1009.875	3977.194	0.000	37493.84
STOCK_ENV	Department-level stock of patents in environmental technologies	Own elaboration (OECD REGPAT 2018)	1056	95.580	375.473	0.000	3420.506
STOCK_NENV	Department-level stock of patents in non-environmental technologies	Own elaboration (OECD REGPAT 2018)	1056	914.295	3604.062	0.000	34073.33
COH	Knowledge coherence	Own elaboration (OECD REGPAT 2018)	1056	-0.314	0.371	-2.810	0.959
KV_Y	Knowledge variety (entropy index) for environmental technologies	Own elaboration (OECD REGPAT 2018)	1056	0.144	0.211	0.000	2.000
RKV_Y	Related knowledge variety for environmental technologies	Own elaboration (OECD REGPAT 2018)	1056	0.038	0.114	0.000	2.000
UKV_Y	Unrelated knowledge variety for environmental technologies	Own elaboration (OECD REGPAT 2018)	1056	0.106	0.127	0.000	0.531

Key explanatory variables

Because of the specific and complex nature that characterises the knowledge base of eco-innovative activities (Colombelli and Quatraro 2019), using the typical pool of covariates used mainly for manufacturing entries may imply some bias in the analysis of the location determinants of environmental technology-based firms. For this reason, a set of specific factors that are found to foster innovation related to environmental technologies should be considered (see for instance, Corradini 2019, Colombelli and Quatraro 2019 or Quatraro and Scandura 2019).

Among them, one of the most important factors encouraging the location of eco-innovative activity is knowledge spillovers from the innovative activities of incumbent firms (Acs et al. 2009; 2013). To capture the capacity of regions to generate and accumulate knowledge, we add knowledge stock indicators defined as the accumulated number of patent applications (STOCK_ALL) relying on the permanent inventory method. The same variable has also been built for environmental-based patents (STOCK_ENV) as well as for its complement, that is, for non-environmental-based patents (STOCK_NENV) as they may differently affect the entry of eco-innovative firms (Colombelli and Quatraro 2019) (see Annex A for the details).

Besides the accumulation of knowledge, when assessing the regional factors that may incentivise the entry of eco-innovative firms, it is important to consider the nature of the local knowledge base (Colombelli and Quatraro 2018, 2019). To do so, we follow the empirical approach based on the recombinant (multidimensional) knowledge approach proposed by Colombelli and Quatraro (2019). According to this approach, it is possible to examine the technological classes assigned to each of these patents. Each technological class l is linked to another class j when the same patent is assigned to both classes, and then, we can refer to the co-occurrence of classes l and j within the same patent. Thus, the higher the number of patents assigned to both classes l and j , the stronger the link between both classes. On this basis, we calculate a set of variables measuring the degree of variety and complementarity that characterise the local knowledge base of French *départements*.

First, knowledge variety (KV_Y) measures the degree of technological diversification of the knowledge base. The measurement of knowledge variety is based on the information entropy index applied to the analysis of the geography of knowledge spillovers (Frenken and Nuvolari 2004; Frenken et al. 2007). However, in this paper we adopt the multidimensional version of these indicators. Unlike studies using one-dimensional entropy, the analysis based on co-occurrences of technological classes allows an entropy index to be built up on the distribution of the co-occurrences of technological classes in patents, instead of considering the distributions of the single technological classes. In other words, it allows us to identify the degree of variety of knowledge combinations (Colombelli and Quatraro 2018).

This indicator can be further decomposed into related and unrelated knowledge varieties. In this paper we propose an application of these multi-dimensional variety indicators to the domain of environmental technologies (RKV_Y and UKV_Y). While in previous analysis that used variety indicators as key variables explaining the location determinants of green start-ups (Corradini 2019, Colombelli and Quatraro 2019), the degree of association among all technological classes was considered, in the present paper, we focus on the association of environmental technological classes with other technologies. In this way, we can disentangle the degree of diversity of the local knowledge base in terms of environmental inventions that was drowned out when using the former approach (see Annex B for more details). Concretely, RKV_Y measures the degree of technological differentiation within the macro-field or, in other words, the average variety within the technological subclasses belonging to the environmental class Y. UKV_Y measures the degree of technological differentiation across macro-fields, that is the average variety between the environmental technology class Y with the other subsets of technologies different from the Y class. This application is particularly relevant for the purposes of our paper since new environmental technologies rely more on the recombination of different pieces of knowledge that are more complex and often cognitively distant than non-environmental technologies do (Berbiere et al. 2016; Orsatti et al. 2017; Fusillo 2019; Quatraro and Scandura 2019).

Second, to account for the degree of complementarity among the technological classes we have calculated the knowledge coherence indicator (COH) that measures the average degree of relatedness or complementarity of the technologies that makes up the knowledge base of each *département*. This indicator is based on the works of Nesta and Saviotti (2006), Nesta (2008) and Quatraro (2010). Concretely, COH is computed by analysing the co-occurrence of technological classes within patent applications and it is based on how frequently technological classes are combined in use. Details about the calculations are provided in Annex C.

Finally, regional capabilities to generate eco-innovations may be positively associated, to some extent, with the political support to environmental policies (Santoalha and Boschma 2019). In the same way, local efforts to reduce the environmental impact of economic activities made either at the initiative of the establishment or to comply with the current legislation should incentivise the generation of environmental technologies (Requate 2005; Carrion-Flores et al. 2010; Barbieri et al. 2016; Yue et al. 2011). To capture the population's support for environmental policies and the environmental engagement and efforts made by the industry to reduce the environmental impact, we

include the share of votes for the ecologist party at the French national elections (VOTE_ECO)⁴¹ and the total amount of investments for the protection of the environment (ECO_INVEST).⁴²

Control variables

Socioeconomic characteristics such as unemployment (UNEMP), population density (POP_DEN) or specialised human capital (SCITECH) should be controlled for. Regarding the impact of unemployment on the creation of innovative firms, unemployment may be associated more with a Schumpeter (pull) effect than a refugee (push) effect. According to the Schumpeter effect, the creation of new firms is mainly driven by innovative ideas or market opportunities such as in the case of technology-based firms. Thus, the conditions leading to higher unemployment rates may deter the creation of new eco-innovative firms (Storey 1991; Fritsch 2008). In the French case, Aubry et al. (2015) found that start-ups in all sectors in France are mainly explained by a refugee effect which limits the growth potential for new businesses in most regions, but this effect may differ for eco-innovative firms. The refugee effect implies that the creation of firms may be a strategy to escape from unemployment when the individual is in bad conditions in the labour market (Oxendfelt 1943). Densely populated areas may be associated with more intensive interaction and higher productivity as well as with a higher potential demand. In line with previous studies (Audretsch et al. 2010; Rodriguez-Pose and Hardy 2015), this measure serves as a proxy for agglomeration and urbanisation economies not directly related to technological activity. The role of different kinds of university knowledge in the creation of new ventures has been highlighted in previous studies (Woodward et al. 2006; Kirchhoff et al. 2007; Acosta et al. 2011; Bergmann et al. 2016) such as the knowledge embedded in university graduates that are employed in science and technology industries. Geography and institutional issues also matter (Guimarães et al. 2000), as firms need good accessibility to services provided in cores, so it is necessary to control for accessibility to main cities such as Paris (*DIST_PARIS*). Proximity to the most important city in the country may capture on the one hand, a potential competition effect in

⁴¹ To elaborate the variable VOTE_ECO it is assumed that a given election is only relevant for a given five-year period if the year of the election is lagged with at least three-years from the start of a five-year period (Santoalha and Boschma 2019). According to that, results in the first round of the French national elections of 2002 are associated with the period 2003-2009; results in 2007 are associated with the period 2010-2013; and results in 2012 are associated with the period 2014-2015.

⁴² The data comes from a survey whose aim is to update knowledge of the amount and nature of studies, investments (equipment entirely dedicated to environmental protection, purchases of more efficient equipment in terms of the environment, etc.), and current expenditures to protect the environment in the industry (please, visit <https://www.insee.fr/fr/metadonnees/source/serie/s1232>, for more details). The data is available at NUTS2, then to compute the NUTS 3 corresponding variables, we weight the NUTS 2 variables for the NUTS 3 share of regional GDP.

view of agglomeration of firms in that area and, on the other hand, a competitive advantage in terms of the services and amenities located in and around Paris.

3.4 Econometric strategy

To analyse the location determinants of eco-innovative firms and their relationship with the technological knowledge base and composition of the *départements*, we estimated the eco-innovative firms' entry as a function of the set of technology indicators controlling for local characteristics. The specification to be estimated is formally defined as follows:

$$ECO_ENTRY_{it} = \alpha + \beta_1 STOCK_ALL_{it-1} + \beta_2 STOCK_ENV_{t-1} + \beta_3 STOCK_NENV_{t-1} + \beta_4 COH_{t-1} + \beta_5 KV_Y_{t-1} + \beta_6 RKV_Y_{it-1} + \beta_7 UKV_Y_{it-1} + \beta_8 UNEMP_{t-1} + \beta_9 POP_DEN_{t-1} + \beta_{10} SCITECH_{t-1} + \beta_{11} DIST_PARIS_t + \beta_{12} ECO_INVEST_{t-1} + \beta_{13} VOTE_ECO + \delta_{it} + \varepsilon$$

where δ represents the time and *département* dummies and ε is the disturbance. The dependent variable, ECO_ENTRY_{it} , is defined as a dichotomous variable being equal to 1 for those *départements* that experienced at least one eco-innovative entry in year t , and 0 otherwise since less than 1% of the *départements* experienced a multiple entry per year.⁴³

Considering the nature of our dependent variable, we estimate this model by a Generalised Linear Model (GLM) following a negative binomial distribution and logit link function via maximum likelihood. A GLM framework assuming a negative binomial (BN) distribution for the conditional expectation of the number of new eco-innovative firms in each *département*, provides a relatively flexible framework for the analysis of such data. The model includes time and *département* fixed effects. Results are robust to logit and probit model estimates. Still, as the fixed-effects logit estimator is potentially inconsistent in the presence of serial correlation and heteroscedasticity (Wooldridge 2010), the GLM is preferred.⁴⁴ To deal with that, cluster robust standard errors are included in the GLM regression to account for potential heterogeneity and serial dependence over time.

The set of independent variables are one period lagged to avoid simultaneity problems. Moreover, the set of knowledge variables are not simultaneously included in the model in order to avoid multicollinearity problems.

⁴³ The focus on the entry of new innovative firms specialising in environmental technologies implies that in a year t and a *département* i the mean maximum number of entries would be equal to 3. The nature of this data implies that by using our dichotomic variable we can, to a great extent, explain the capacity of the region to incentivise the successful entry into the market of environmental technologies, as Corradini (2019) also suggested.

⁴⁴ As robustness check, the same specification has also been estimated by using non-linear logit and probit models and results slightly vary. Results are available upon request.

Firm location determinants may extend beyond *départements* limits and if this potential spatial dependence is not considered, results may be biased and inconsistent (Anselin, 1988). To account for spatial dependence, we estimate the eco-innovative entries by applying spatial econometrics for panel data (Elhorst, 2010; 2014). Concretely, a Spatial Durbin Model (SDM) was adopted through a row-standardised contiguity weighting matrix according to previous contributions for the case of French metropolitan *départements*.⁴⁵

The SDM includes the spatial lag of the dependent variable as well as the spatial lag of one or more exogenous variables in the model. Thus, in this paper we include in the SDM the spatial lag for the key variables capturing the local knowledge structure. The choice of the SDM is justified for three main reasons. First, it is considered the best performing estimator among the set of spatial dependence models for panel data (i.e., Spatial Lag Model, Spatial Autoregressive Model and the Spatial Autocorrelation Model). It also allows for the estimation of the direct and indirect effects of the lagged variables on the dependent variable (i.e., the effects in the main region and in the neighbouring ones) (Elhorst, 2014). And second, the SDM is the most appropriate spatial model for the purposes of this paper since it allows us to capture any source of spatial dependence in terms of knowledge spillovers and firm location in the environmental domain spreading beyond geographical limits (Colombelli and Quatraro, 2018; Feng and Chen, 2018).⁴⁶

3.5 Results

The GLM results for the location determinants of eco-innovative firms' entries are reported in Table 3.2. As mentioned above, all variables are one period lagged in order to avoid simultaneity problems and all regressions include region and time fixed effects.

We first discuss the results for our key variables, that is, knowledge indicators. It is important to notice that the set of knowledge variables is not simultaneously included in the model in order to avoid multicollinearity problems. The first four specifications, shown in columns 1, 2, 3 and 4, are the results for the estimation including the knowledge stock of patents in all technologies, environmental and non-environmental, respectively. According to our results, differences in the accumulated knowledge capital stock are positive but not significant for the creation of new eco-innovative firms. Anyway, if we compare both coefficients, the impact of the stock of environmental patents seems to be slightly

⁴⁵ Other spatial weighting definitions were considered such as 5 nearest neighbours or an inverse distance-based matrix. Even so, the best fit of the model is obtained when we rely on a row-standardised contiguity weighting matrix, an approach that has already been used in previous contributions for the case of French metropolitan *départements* (see for instance, Elhorst and Fréret (2009)).

⁴⁶ More details on the test procedure to find out the most appropriate model can be found in section 5.1.

more important. In column 4, when adding both types of knowledge stock to the model they remain non-significant, but the stock of environmental patents now turns negative. These results hold without adding population density into the model due to the high correlation with these variables. Thus, these results answers our RQ1 and imply that 1) there is not a predominant knowledge base for the creation of eco-innovative firms and, 2) the local accumulated knowledge stock is not enough to characterise the knowledge generation capacity at a regional level and that it is necessary to account for the nature behind of the local knowledge base in the following models.

The creation of eco-innovative firms may be affected by the diversity of knowledge combinations specially associated with environmental technologies. This is what we test by adding the KV_Y, RKV_Y and UKV_Y indicators shown in columns 5, 6, 7 and 8.⁴⁷ In this case, even though the estimates for all these variables are positive, only those of unrelated knowledge variety for environmental technologies are significant, a result that holds when it is jointly added to the model with related knowledge variety for environmental technologies. Thus, this result answers to RQ2 and it may imply that the creation of eco-innovative firms is favoured by the possibility of combining novel pieces of knowledge coming from other technologies with that of environmental ones rather than new combinations of existing knowledge in the environmental field. Indeed, the fact that only unrelated knowledge for environmental technologies is significant suggests that the more diverse the technologies carried out within the *département* are, the higher likelihood of having an eco-innovative entry in the *département*. Still, the average coherence (COH) of the local knowledge base shows a positive but non-significant coefficient (see column 9).

Other important factors that may explain regional differences on the creation of eco-innovative firms are the environmental political support and local sensitivity to environmental issues. This fact is supported by the positive and significant effect of that the total amount of investments for the protection of the environment (ECO_INVEST) has on the likelihood of creating an eco-innovative firm across all specifications. The share of the vote for ecological parties is also positive, but just significant in the last specification (column 8).

Regarding the control variables, we observe positive and significant effects for population density and distance to Paris across the different model specifications. These results support the fact

⁴⁷ Although we focus here on the variety indicators for environmental technologies, we have also calculated the usual KV, RKV and UKV considering the diversity across and within all technological classes. However, when they were included into the model, results were not significant for any of the variety indicators. We guess that this may be explained by the specific nature of environmental technologies that requires a greater recombination of different pieces of knowledge that are more complex and cognitively distant, compared to non-environmental technologies (Berbiere et al. 2016; Orsatti et al. 2017; Quatraro and Scandura 2019). Results are available upon request.

that densely populated areas facilitate the entry of eco-innovative firms due to the agglomeration advantages arising from the concentration of a diverse range of economic and innovative activities (Audretsch et al. 2010; Rodriguez-Pose and Hardy 2015). According to these results, the larger distance to Paris, the higher the likelihood of eco-innovative firm entry. Even if we should expect that this effect is negative since they may have more difficulties in establishing networks and access to specialised research and development centres which are highly concentrated in and around the French capital, a larger distance to Paris may also capture a potential competition effect in view of agglomeration of firms in that area. Instead, the estimates for unemployment are negative and significant across all model specifications. This result is consistent with the fact that for eco-innovative firms, unemployment may be rather associated with a Schumpeter (pull) effect than a refugee (push) effect. Finally, the estimates for employment in science and technology sectors with tertiary education are not statistically significant. According to that, the importance of specialised employment is probably blurred by the influence of other variables capturing knowledge spillovers such as population density as well as knowledge base indicators.

Spatial econometrics analysis

These results provided interesting evidence about the effects of the local knowledge base on the creation of eco-innovative firms' entry. However, it is important to account for the spatial dimension of these effects (Elhorst 2014). Thus, we implemented an SDM with the aim to understand the effects of the spatial lag of the set of knowledge base indicators as well as the dependent variable. The SDM was estimated using the version 1.4-11 *splm* free package for R, which allows for the maximum likelihood estimation of spatial panel models (Millo and Piras 2012). To further justify the use of the SDM, we followed the test procedure to find out which model is the most appropriate model to our data proposed by Anselin (2010; 2014). First, we estimate the OLS model and test whether the spatial lag model (SLM) or the spatial error model (SEM) is more appropriate. To do so, we apply the robust Hausman specification test for spatial panel data models LM-tests proposed by Hausman (1978). According to our results, we reject the null hypothesis, that is, we confirm the presence of spatial autocorrelation in the error terms, then the SDM it is recommended. Indeed, alternative Spatial Lag Models (SLM) or Spatial Error Models (SEM) should be approached if either the spatial lag of the dependent variable or the key explanatory variables turn out to be not significant in the regressions, which is not our case.

The spatial econometrics results are shown in Table 3.3. The sign and significance of the control variables are pretty consistent with the previous estimations, except for unemployment. Such result may be explained by the fact that both a positive and negative effect on firms' creation may coexist and this result is in line with previous findings (Storey 1991). When we look at the spatial lag

of the dependent variable, that is the entry of eco-innovative firms in neighbouring *départements*, we found a positive and significant effect on the entry of eco-innovative firms in the *département* of reference and this result remains stable across almost all specifications. In other words, this result implies that any increase in the creation of eco-innovative firms in neighbouring *départements* will have positive effects on the likelihood of eco-innovative entry in the local *département*. This can be interpreted as a positive contagious effect according to which the entrepreneurial dynamics in environmental technologies in neighbouring regions may encourage the entry to eco-innovative markets in the local *département*. Besides that, when considering any source of spatial dependence in the model we found interesting results. Now the coefficients of each of the local stock of knowledge capital (see columns 1, 2, 3) and knowledge diversity (see columns 4-6) turn out to be positive and significant when their spatial lags are considered. The larger effect is still found in the case of the unrelated variety for environmental technologies which is consistent with our previous results. However, the estimates for their spatial lagged counterparts are non-significant. These results answer our RQ 3 and 4 and suggest two main facts. First, important spatial dynamics across French *départements* exist in the creation of new eco-innovative firms, but they are mainly explained by the development of these technological activities in neighbouring *départements*. Second, the development of a diverse but specialised knowledge base on environmental technologies at the local level is a relevant factor for the creation of these activities.

Table 3.2 GLM logit regression estimates

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
<i>Socioeconomic factors</i>	POP_DEN	-	-	-	-	0.013** (0.005)	0.013** (0.005)	0.013** (0.005)	0.013** (0.005)	0.013** (0.005)
	UNEMP	-1.804*** (0.578)	-1.829*** (0.588)	-1.801*** (0.576)	-1.837** (0.605)	-1.559*** (0.542)	-1.594*** (0.542)	-1.572*** (0.544)	-1.613*** (0.554)	-1.679*** (0.526)
	SCITECH	-3.049 (11.51)	-3.234 (11.56)	-3.029 (11.50)	-3.647 (11.66)	-2.213 (11.42)	-2.308 (11.39)	-1.644 (11.48)	-1.038 (11.50)	-1.438 (11.32)
	DIST_PARIS	0.577*** (0.217)	0.578*** (0.202)	0.578** (0.232)	0.609* (0.223)	0.602** (0.247)	0.608 (0.187)	0.612*** (0.142)	0.628*** (0.171)	0.637** (0.324)
<i>Environmental political support</i>	ECO_INVEST	0.030* (0.016)	0.029* (0.016)	0.030* (0.016)	0.032* (0.016)	0.037** (0.016)	0.037** (0.016)	0.037** (0.016)	0.038** (0.016)	0.037** (0.016)
	VOTE_ECO	0.745 (0.482)	0.734 (0.482)	0.747 (0.482)	0.788* (0.475)	0.744 (0.486)	0.765 (0.489)	0.758 (0.482)	0.789 (0.483)	0.806* (0.479)
<i>Knowledge indicators</i>	STOCK_ALL	0.000 (0.000)	-	-	-	-	-	-	-	-
	STOCK_ENV	-	0.001 (0.002)	-	-0.009 (0.013)	-	-	-	-	-
	STOCK_NENV	-	-	0.0002 (0.0003)	0.001 (0.001)	-	-	-	-	-
	KV_Y	-	-	-	-	1.008 (0.764)	-	-	-	-
	RKV_Y	-	-	-	-	-	1.171 (1.423)	-	-1.117 (1.890)	-
	UKV_Y	-	-	-	-	-	-	2.211* (1.342)	2.928* (1.684)	-
	COH	-	-	-	-	-	-	-	-	0.241 (0.790)
	Constant	-14.84*** (2.604)	-13.87*** (2.632)	-14.87*** (1.380)	-14.255*** (1.077)	-17.72*** (3.066)	-17.50 (2.975)	-17.89 (2.017)	-17.93*** (1.974)	-17.32*** (3.834)
N	960	960	960	960	960	960	960	960	960	
Départements	96	96	96	96	96	96	96	96	96	
Time and département FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Log-pseudolikelihood	-147.236	-147.266	-147.082	-147.082	-145.666	-146.104	-145.313	-145.202	-146.314	

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Besides the SDM estimation results, the estimation of the direct and indirect effects through the implementation of a partial derivative approach allow us to fully capture spatial dynamics effects (Pace and Le Sage 2009). Table 3.4 reports the direct, indirect and total effects for the set of knowledge indicators. If we focus on the direct effects, that is, the intra-regional impact of the explanatory variables, we found a positive and significant effect for the cumulated stock of patents in all kinds of technologies as well as for each of the knowledge variety indicators. The only exception is the measure of relatedness (coherence) which is positive but not significant. This result suggests that the variety of combinatorial patterns among the environmental and non-environmental technologies in the *département* positively affects the creation of eco-innovative firms. Regarding the indirect effects, that is the inter-regional impact of explanatory variables, it seems that they are positive but not statistically significant. These findings confirm our previous results highlighting the limited/local spatial effect on eco-innovative firm creation. In other words, the impact of knowledge spillovers mainly accrues within the *département* where the entry takes place, at least for the French case.

3.6 Discussion and conclusions

This paper contributes to the literature on the economy of innovation by analysing the location determinants of new innovative firms highly specialised in environmental technologies in the French metropolitan *départements* over the period 2003-2013. In particular, we study the role played by the features of the local knowledge base on the creation of new eco-innovative firms as well as the spatial dependence on this process by computing a specific set of knowledge indicators that capture the *départements*' specific recombination of technologies that define the capacity to generate environmental knowledge (patents).

The results of this work contribute to the academic debate on the geography of innovation in many ways and provide more evidence, in the case of environmental technologies, of some of the current challenges of the literature of regional diversification as Boschma (2016) pointed out. First, our results shed light on the impact of knowledge recombination process behind environmental inventions in the creation of new eco-innovative firms. Concretely, we found that the level of local knowledge stock is not enough to explain a higher likelihood of eco-innovative firms' entry. However, when we consider the spatial dimension, we found that pre-existing accumulated knowledge in both environmental and non-environmental technologies matters at local level, supporting the findings of Montresor and Quatraro (2020).

Table 3.3 Spatial Durbin Model Estimates

DEP. ECO_ENTRY	VAR. :			(4)	(5)	(6)	(7)
	(1)	(2)	(3)				
W_ECO_ENTRY	0.073 (0.046)	0.073 (0.046)	0.073 (0.046)	0.084* (0.046)	0.084* (0.046)	0.082* (0.046)	0.08* (0.046)
POP_DEN	-	-	-	0.001*** (0.000)	0.001*** (0.001)	0.001*** (0.01)	0.001*** (0.000)
UNEMP	0.017* (0.01)	0.017* (0.01)	0.017* (0.01)	0.015 (0.01)	0.015 (0.01)	0.015 (0.01)	0.014 (0.01)
SCITECH	0.154 (0.336)	0.138 (0.336)	0.158 (0.336)	0.102 (0.339)	0.154 (0.339)	0.133 (0.339)	0.233 (0.34)
DIST_PARIS	-	-	-	-	-	-	-
ECO_INVEST	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
VOTE_ECO	0.037 (0.023)	0.037 (0.023)	0.036 (0.023)	0.032 (0.023)	0.028 (0.023)	0.032 (0.023)	0.025 (0.024)
STOCK_ALL	0.000*** (0.000)	-	-	-	-	-	-
STOCK_ENV	-	0.0008*** (0.0001)	-	-	-	-	-
STOCK_NENV	-	-	0.000*** (0.000)	-	-	-	-
KV_Y	-	-	-	0.132*** (0.000)	-	-	-
RKV_Y	-	-	-	-	0.182** (0.062)	-	-
UKV_Y	-	-	-	-	-	0.208*** (0.061)	-
COH	-	-	-	-	-	-	0.024 (0.028)
WX	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.092 (0.066)	-0.149 (0.116)	-0.134 (0.114)	-0.032 (0.042)
N	960	960	960	960	960	960	960
Time FE	Y	Y	Y	Y	Y	Y	Y
Département FE	Y	Y	Y	Y	Y	Y	Y
F-Test	1.469**	1.469**	1.469**	1.309**	1.349**	1.327**	1.408***
Hausman Chi ²	34.16***	35.76***	33.846***	19.82**	18.36**	19.23**	18.39**

Robust Standard Errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 3.4 Direct, indirect and total effects of the relevant variables after SDM estimation

	Direct	Indirect	Total
STOCK_ALL	0.0001*** (0.000)	0.0000 (0.000)	0.0001*** (0.000)
STOCK_ENV	0.0007*** (0.000)	0.000 (0.000)	0.0008*** (0.000)
STOCK_NENV	0.0001*** (0.000)	0.0000 (0.000)	0.0001*** (0.000)
COH	0.0212 (0.027)	0.0012 (0.002)	0.0224 (0.028)
KV_Y	0.1267*** (0.034)	0.0081 (0.007)	0.1348*** (0.037)
RKV_Y	0.1820** (0.059)	0.0113 (0.009)	0.1933** (0.065)
UKV_Y	0.1918** (0.067)	0.0119 (0.011)	0.2038** (0.072)
Control variables	Y	Y	Y
N	960	960	960
<i>Départements</i>	96	96	96

Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

When it comes to understand the nature behind the regional knowledge base by our specific indicators for environmental knowledge recombination capacity of *départements*, we found that unrelated knowledge variety for environmental technologies (the average variety between environmental and non-environmental technologies classes making up environmental patents) plays a key role in explaining the location of eco-innovative firms. These results are in line with previous findings and support the idea that the creation of environmental technology-based firms benefits from the combination of diverse knowledge in unrelated domains (Castaldi et al. 2015; Barbieri et al. 2018, 2020; Barbieri and Consoli 2019,; Quatraro and Scandura 2019). However, they do not corroborate those contributions that find a significant effect of relatedness and related variety on the entry of eco-innovative firms (Colombelli and Quatraro 2019; Corradini 2019). In fact, the greater significance of unrelated variety for environmental technologies suggests that due to the higher complexity and degree of novelty that characterise environmental technologies they may require a greater recombination of different pieces of knowledge that are cognitively distant, compared to non-environmental technologies (Barbieri et al. 2016; Orsatti et al. 2017; Quatraro and Scandura 2019). When accounting for spatial dependence in our model, we found that the creation of eco-innovative firms in neighbouring *départements* may incentivise the eco-innovative entry in the local *département*, while the

impact of knowledge spillovers from both related and unrelated technologies on the creation of eco-innovative firms is quite local, that is, they remain within the boundaries of each *département*. Even though there are no contributions applying spatial econometrics to analyse the creation of eco-innovative firms, the results confirm those contributions suggesting that spatial path dependence and regional dynamics are important in fostering eco-innovation (Colombelli and Quatraro 2019 or Corradini 2019). Finally, our results also confirm previous contributions arguing that environmental regulations may have rather a pull-effect on the economy to foster the creation of eco-innovative firms (Requate 2005; Carrion-Flores et al. 2010; Barbieri et al. 2016; Yue et al. 2011).

Even though our results focus on the French case and should not be generalised to other countries, they have important territorial implications on the transition process to green regional development providing valuable evidence of the role that local specificities and the extension of knowledge spillovers play on the formulation of the smart specialisation policies such as the RIS3 developed in the European context (European Commission 2012). First, the significant and robust effect of unrelated variety for environmental technologies on eco-innovative firms' entry suggests that policies should account for the context-specific environmental recombination of existing activities in which the *départements* are specialised. For example, those regions specialised in the automotive industry would have a comparative advantage in developing the electric car in comparison to regions where the automotive industry is not developed. And this is a key implication for the success of RIS3 policies, since it implies that even regions that are not specialised in environmental technologies can also foster the creation of eco-innovative activities through the recombination of pre-existing non-environmental and new environmental knowledge (Montresor and Quatraro 2020). Second, our results highlight the importance of environmental political support. In this regard, environmental regulation may exert an incentive for firms to introduce innovations have a key role in the creation eco-innovative firms. Finally, the positive neighbouring effect in terms of entrepreneurial dynamics in environmental technologies appears also to be consistent with policies supporting eco-innovative entrepreneurship at regional level such as the Green Action Plan for SMEs (European Commission 2014) or its French version, the *Programme d'investissement d'avenir* (PIA) (ADEME 2018). However, given that the spatial scope of knowledge indicators is quite local, the effectiveness of policies aimed at enhancing knowledge spillovers for environmental technologies should carefully assess the local specificities rather than be designed at a regional or national level consistent with the Smart Specialisation logic.

Despite all this, this study does have some limitations. By relying on patents data to capture eco-innovative firms' entry we are not able to encompass the whole set of firms that innovate in the environmental domain since not all innovative firms may be able to apply for patents. Nevertheless, with this approach we can focus on highly technological-intensive firms operating in the

environmental domain. In this regard, the use of survey data on entrepreneurs working on the environmental domain would provide additional evidence to support our findings. Furthermore, notwithstanding the use of lagged explanatory variables to reduce any potential endogeneity in our estimates, further studies may be required to shed more definite light on the causal relationships in our findings. Finally, even though the analysis at *départementale* level provides remarkable results in terms of policy implications, any future research should focus on analysing this issue at micro-level (i.e., cities, metropolitan areas, clusters, etc.) making use of GIS techniques to account for the impact of innovation ecosystems on the creation of eco-innovative firms.

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Appendix 3.1: The implementation of knowledge spillovers⁴⁸

A. Knowledge stock

To measure the local knowledge stock (STOCK_ALL) based on patent applications we calculate the accumulated stock of past patent applications applying the permanent inventory method as follows:

$$STOCK_ALL_{it} = h_{it} + (1 - \delta)STOCK_{it-1} \quad (A0)$$

where h_{it} is the flow of patent applications, δ is the rate of obsolescence of 10%⁴⁹, i is the region and t is the time period. This measure has also been calculated for both non-environmental (STOCK_NENV) and environmental technologies (STOCK_ENV).

B. Knowledge variety

Our measure of knowledge variety is based on the information entropy index by following a multidimensional approach proposed by (Colombelli and Quattraro 2019).⁵⁰ Indeed, as we argued in Section 2 and 3, we focus on the association of environmental technologies with other technologies.

Let us consider a pair of events (X_l, Y_j) , and the probability of their co-occurrence p_{lj} . A two-dimensional total variety (KV_Y) measure can be expressed as follows:

$$KV_Y = H(X, Y) = \sum_l \sum_j p_{lj} \log_2 \left(\frac{1}{p_{lj}} \right) \quad (A1)$$

Where p_{lj} is the probability that two technological classes l and j co-occur within the same patent. The measure of multidimensional entropy focuses on the variety of co-occurrences or pairs of technological classes in patent applications, and provides an index of how much the creation of new knowledge is focused in a narrower set of possible combinations.

The total index can be decomposed into ‘within’ and ‘between’ parts, whenever the events under study can be aggregated into smaller number of subsets. Within-group entropy measures the average degree of variety within the subsets; between-group entropy focuses on the subsets and measures the average degree of variety across them.

Let the technologies l and j belong to the subsets g and z of the classification scheme, respectively. If one allows $l \in S_g$ and $j \in S_z$, it is possible to write:

⁴⁸ This section builds on Quattraro (2010) and Colombelli and Quattraro (2017; 2019).

⁴⁹ See Soete and Patel (1985) for similar approaches. Alternative rates of obsolescence have been applied with no significant variations on the final calculations.

⁵⁰ See Saviotti (1988), Frenken and Nuvolari (2004) and Stirling (2007) for further details on the definition and properties of this index.

$$P_{gz} = \sum_{l \in S_g} \sum_{j \in S_z} p_{lj} \quad (A2)$$

Which is the probability of observing the couple lj in the subsets g and z , while the intra subsets variety can be measured as follows:

$$H_{gz} = \sum_{l \in S_g} \sum_{j \in S_z} \frac{p_{lj}}{P_{gz}} \log_2 \left(\frac{1}{p_{lj}/P_{gz}} \right) \quad (A3)$$

The weighted within-group entropy or related variety for environmental technological classes (RKV_Y) can therefore be written as follows:

$$RKV_Y = \sum_{g=1}^G \sum_{z=1}^Z P_{gz} \quad (A4)$$

Between group or unrelated variety for environmental technological classes (UKV_Y) can instead be calculated using the following equation:

$$UKV_Y \equiv H_Q = \sum_{g=1}^G \sum_{z=1}^Z P_{gz} \log_2 \left(\frac{1}{P_{gz}} \right) \quad (A5)$$

According to the decomposition theorem, the total entropy $H(X,Y)$ can be re-written as follows:

$$KV_Y = H_Q + \sum_{g=1}^G \sum_{z=1}^Z P_{gz} H_{gz} \quad (A6)$$

The first term on the right-hand-side of Eq. (A6) is the between-entropy and the second term is the weighted within entropy for environmental technological classes.

C. Knowledge coherence or relatedness

The degree of complementarity among the technological classes composing the local patent's portfolio have been calculated in different steps for the 96 French départements (Nesta and Saviotti 2006; Nesta 2008; Quatraro 2010).

Following Teece et al. (1994), the weighted average relatedness (WAR_l) is defined as the degree to which technology l is related to all other technologies $j \neq l$ in the regions' patent portfolio, weighted by patent count P_{jt} .

$$WAR_{lt} = \frac{\sum_{j \neq l} \tau_{lj} P_{jt}}{\sum_{j \neq l} P_{jt}} \quad (A7)$$

Finally, the coherence of the region's knowledge base at time t is defined as the weighted average of the WAR_{lt} measure:

$$COH_t = \sum_l WAR_{lt} \times \frac{P_{lt}}{\sum_l P_{lt}} \quad (A8)$$

The technological relatedness measure τ_{lj} indicates that the utilisation of technology l also implies the use of technology j , in order to perform specific functions that are not reducible to their independent use.

To set the τ parameter first we built a relatedness matrix as follows (Nesta, 2008). Let the technological universe consist of k patent applications. Let $P_{jk} = 1$, if the patent k is assigned to technology j [$j = 1, \dots, n$], and 0 otherwise. The total number of patents assigned to technology j is $O_j = \sum_k P_{jk}$. Similarly, the total number of patents assigned to technology m is $O_m = \sum_k P_{mk}$. Since two technologies may be present within the same patent, $O_j \cap O_m \neq \emptyset$, the number of observed co-occurrences of technologies j and m is $J_{jm} = \sum_k P_{jk}P_{mk}$. By applying this relationship to all the possible pairs, we obtain a square matrix Ω ($n \times n$) where the generic cell is the observed number of co-occurrences:

$$\Omega = \begin{pmatrix} J_{11} & \dots & J_{n1} \\ \vdots & \ddots & \vdots \\ J_{1n} & \dots & J_{nn} \end{pmatrix} \quad (\text{A9})$$

We can assume that the number x_{jm} of patents assigned to both the j and m technologies is a hypergeometric random mean and variance variable:

$$\mu_{jm} = E(X_{jm} = x) = \frac{O_j O_m}{K} \quad (\text{A10})$$

$$\sigma_{jm}^2 = \mu_{jm} \left(\frac{K-O_j}{K} \right) \left(\frac{K-O_m}{K-1} \right) \quad (\text{A11})$$

If the observed number of co-occurrences J_{jm} is larger than the expected number of random co-occurrences μ_{jm} , then the two technologies are closely related: the fact that the two technologies occur together in the number of patents x_{jm} is not random. Thus, the measure of relatedness is given by the difference between the observed and the expected number of co-occurrences, weighted by their standard deviation:

$$\tau_{jm} = \frac{J_{jm} - \mu_{jm}}{\sigma_{jm}} \quad (\text{A12})$$

It should be noted that this measure of relatedness has lower and upper bounds: $\tau_{jm} \in] - \infty; +\infty[$. Moreover, the index shows a similar distribution to a t-student distribution; so, if $\tau_{jm} \in] - 1.96; +1.96[$, one can assume the null hypothesis of non-relatedness of the technologies. Therefore, the technological relatedness matrix Ω can be considered a weighting scheme to evaluate the technological portfolio of regions

Conclusion générale

Afin de faire face aux défis environnementaux auxquels l'humanité est confrontée, il est crucial de mettre en place des mesures d'urgence et il est nécessaire que l'ensemble des acteurs économiques soient impliqués. Les entreprises se trouvent fortement touchées car elles sont confrontées à des contraintes relatives à la rareté des ressources et à la gestion des externalités négatives dont elles sont responsables, notamment la pollution. Elles sont donc amenées à apporter des solutions qui peuvent se matérialiser par le développement d'éco-innovations. De ce fait, les entreprises ont un rôle important à jouer dans l'atteinte des objectifs de développement durable. Par ailleurs, l'éco-innovation représente une opportunité pour les entreprises et les pays afin de faire face à une économie fortement concurrentielle tout en permettant aux économies de s'orienter vers une croissance « durable » (EC, 2011; OCDE, 2010). La nécessité de l'intervention des Etats afin d'accélérer l'activité d'éco-innovation est reconnue au niveau international (EC, 2011).

Ainsi, la compréhension des déterminants de l'éco-innovation est d'une importance capitale afin d'orienter les politiques publiques. L'objectif de cette thèse est d'analyser les facteurs qui influencent la décision des entreprises d'investir dans une activité d'éco-innovation. Nous avons abordé cette question dans différents contextes en utilisant des données originales ce qui nous a permis d'identifier plusieurs spécificités des éco-innovations. Nous avons reconsidéré les principaux facteurs identifiés dans la littérature : les pressions technologiques, les pressions du marché et la politique environnementale. Nous contribuons à cette littérature en intégrant d'autres facteurs internes et externes non pris en compte dans la littérature en raison notamment de l'absence de données. De plus, nous proposons une approche originale en nous intéressant aux aspects entrepreneurial et spatial.

L'urgence de la mise en place des technologies respectueuses de l'environnement est admise au niveau international. Cependant, l'investissement des entreprises dans ces technologies reste conditionné à leur rentabilité. L'éco-innovation se caractérise par un problème de double externalité selon lequel une éco-innovation génère une externalité positive (relative à la diffusion de connaissances qui est commune à l'innovation classique) et elle permet d'éviter une externalité négative environnementale. Ainsi, une entreprise qui investit dans l'éco-innovation supporte un coût additionnel, lié à l'internalisation de l'externalité négative, par rapport aux entreprises concurrentes non environnementales. Cette spécificité de l'éco-innovation peut dissuader les entreprises à investir dans les éco-innovations. Cela a conduit à s'interroger sur l'incidence de l'éco-innovation sur la performance des entreprises. Afin d'apporter des réponses à cette question plusieurs auteurs se sont appuyés sur l'hypothèse de Porter (Dussaux, 2015; Marin, 2014; Marin and Lotti, 2017; Porter, 1991; van Leeuwen and Mohnen, 2017). Celle-ci stipule qu'une réglementation environnementale stricte stimule la découverte et l'introduction d'innovations environnementales et l'efficacité des processus de production. Les économies de coûts qui peuvent donc être générées peuvent être suffisantes pour

compenser à la fois les coûts de mise en conformité à la réglementation et les coûts d'innovation. Cependant, les résultats de la littérature empirique sur la rentabilité des éco-innovations pour les entreprises présentent une diversité considérable, allant de résultats positifs à des résultats négatifs et même non significatifs dans certaines études. Cette absence de consensus met en exergue la complexité de la relation entre l'éco-innovation et la performance des entreprises, et montre la nécessité d'approfondir l'analyse de cette relation. De ce fait, nous avons cherché à comprendre non seulement les facteurs qui motivent les entreprises pour éco-innover mais également l'incidence que peut avoir l'éco-innovation sur l'activité de l'entreprise.

Par ailleurs, la littérature empirique reconnaît la spécificité des stratégies d'éco-innovation adoptées par les Petites et Moyennes Entreprises (PME) par rapport à celles des grandes entreprises et souligne l'importance d'une investigation beaucoup plus approfondie des PME (Aragón-Correa et al., 2008; Bos-Brouwers, 2010). Les PME sont considérées comme participant à la dégradation de l'environnement (Jenkins, 2009), elles peuvent donc être une solution prometteuse. L'argument en faveur des entreprises naissantes est leur forte capacité à développer des innovations radicales (Demirel et al., 2019; Wagner, 2010). L'orientation de ces entreprises est influencée par le dirigeant, leurs pratiques sont alors liées au profil de l'entrepreneur qui a donc un rôle crucial à jouer pour contrer le phénomène de la dégradation de l'environnement (Anderson, 1998; Bocken, 2015; Cohen and Winn, 2007). C'est pourquoi nous nous intéressons dans le deuxième chapitre de cette thèse à une catégorie de PME très peu étudiée dans la littérature sur l'éco-innovation, à savoir les start-ups, en analysant les facteurs qui motivent les dirigeants des start-ups à se lancer dans une activité éco-innovante.

Enfin, nous contribuons à la littérature, en analysant les déterminants spatiaux de la création d'entreprises éco-innovantes, en introduisant notamment des méthodes d'analyse d'économétrie spatiale. Cette approche a reçu peu d'attention dans la littérature et représente donc un sujet d'investigation relativement nouveau.

Les principaux résultats de cette thèse montrent que les instruments de la politique environnementale impactent différemment les types d'éco-innovations (les technologies de traitement des déchets, les technologies d'énergie renouvelable et les technologies d'atténuation du changement climatique) et que les éco-innovations ne sont pas toujours rentables pour les entreprises. D'où la nécessité d'adapter les instruments de politique publique de sorte à améliorer la rentabilité des éco-innovations. L'étude des déterminants de l'éco-innovation dans le cas des start-ups a montré qu'il existe une diversité de profils d'éco-innovateurs. En effet, les start-ups se regroupent en cinq principaux profils qui correspondent à différents déterminants de l'éco-innovation. Nous avons montré empiriquement que les différentes catégories d'éco-innovateurs n'ont pas les mêmes difficultés d'accès aux fonds. Ce qui nous a amené à conclure que les politiques publiques doivent être conçues

en tenant compte de la spécificité de chaque profil. Nous avons également montré que la recombinaison des technologies environnementales et non environnementales et le soutien des autorités publiques aux initiatives environnementales sont les principaux facteurs expliquant la localisation des entreprises éco-innovantes. De plus, en appliquant l'économétrie spatiale, nous avons constaté qu'il existe une dépendance spatiale claire vis-à-vis de leur création alors que l'impact de la diffusion des connaissances est plutôt local.

Dans ce qui suit, nous présentons les résultats obtenus dans chacun des chapitres de cette thèse ainsi que les implications en termes de politique publique.

Le but du **chapitre 1**, intitulé « évaluation de la relation entre la recherche et développement (R&D), l'éco-innovation et la productivité : cas des entreprises françaises », était d'étudier à la fois les déterminants et les effets sur la productivité de l'innovation environnementale. Une analyse empirique, basée sur un modèle CDM (Crépon et al., 1998), est réalisée à partir d'un panel un panel de 2 877 entreprises françaises sur la période 2006-2014.

Les résultats montrent que les facteurs traditionnels qui stimulent l'innovation, tels que la part de marché, le capital fixe, la taille de l'entreprise, ont également un effet significatif sur l'éco-innovation. De plus, la demande actuelle ou prévue des consommateurs de produits respectueux de l'environnement a également un effet positif important sur l'input (R&D environnementale) et l'output (Brevets environnementaux) de l'éco-innovation. Cependant, cette dernière présente certaines spécificités. Les instruments de politique environnementale sous forme de taxes, de redevances, ou de subventions ont un effet positif sur l'investissement en R&D environnementale. De plus, les initiatives volontaires des entreprises pour identifier et réduire leur impact environnemental ont un effet positif élevé sur l'output de l'innovation. Par contre, l'effet de la réglementation environnementale sur l'output de l'éco-innovation s'est révélé non significatif. Les instruments de politique environnementale impactent de façon distincte les différents types d'éco-innovations. En particulier, il s'avère que, les subventions ont un effet positif sur les énergies renouvelables alors que l'adoption de technologies d'atténuation des émissions polluantes repose principalement sur les initiatives volontaires des entreprises.

Les résultats de l'analyse de l'impact de l'éco-innovation sur la productivité ont montré que lorsque l'on différencie les catégories technologiques, seule la mise en place des énergies renouvelables, a un effet positif sur la productivité. Par ailleurs, nous avons montré un rôle important des subventions sur les énergies renouvelables. Par contre, les technologies d'atténuation des émissions polluantes semblent avoir un effet négatif sur la productivité. Plusieurs études empiriques n'ont pas pu valider l'hypothèse de Porter (Dussaux, 2015; Greenstone et al., 2012; Lanoie et al., 2011). Dans notre cas, la validation ou la non-validation dépend du type de technologie considéré. D'après nos résultats, cette hypothèse est en effet validée uniquement pour la catégorie des énergies renouvelables. Nous

concluons que malgré l'effet considérable de la demande des consommateurs de produits respectueux de l'environnement sur le développement de l'éco-innovation, l'effet de l'éco-innovation sur la productivité reste faible. En d'autres termes, les incitations du marché à elles seules ne suffisent pas pour permettre un accroissement considérable de l'innovation environnementale des entreprises. Davantage d'efforts en termes de promotion et de réglementation environnementale semblent nécessaires pour booster ces innovations.

Ces résultats suggèrent que la politique publique doit prendre en compte les spécificités des différentes catégories d'éco-innovations. Les instruments de politique publique existants semblent inadaptés à certaines catégories. Il est admis dans les discours politiques comme dans la littérature économique que l'activité de l'éco-innovation des entreprises a un rôle crucial à jouer collectivement parlant afin d'atteindre les objectifs du développement durable. Cependant, nos résultats indiquent que les éco-innovations ne sont pas toujours rentables pour les entreprises. Il est donc nécessaire d'identifier les instruments adaptés pour chaque type d'éco-innovation afin d'améliorer leur rentabilité pour généraliser leur mise en œuvre par les entreprises.

Le **chapitre 2** est intitulé « Quels sont les déterminants de l'éco-innovation des start-ups françaises ? ». L'objectif de ce chapitre est, dans un premier temps, d'étudier la spécificité des start-ups éco-innovantes par rapport aux start-ups non éco-innovantes en effectuant une analyse discriminante (AD) sur deux thèmes : le capital humain et la politique environnementale. Dans un second temps, une typologie des start-ups éco-innovantes a été développée en utilisant une classification ascendante hiérarchique (CAH). L'analyse a été réalisée à partir de données originales issues d'une enquête que nous avons réalisée auprès de 120 start-ups françaises éco-innovantes et non éco-innovantes en 2019.

En ce qui concerne le capital humain, les résultats montrent que l'accumulation de connaissances de l'entrepreneur notamment à travers des études et une expérience professionnelle en lien avec l'environnement est un facteur qui différencie entre les éco-innovateurs et non éco-innovateurs. En ce qui concerne la politique environnementale, les résultats indiquent que la présence d'une réglementation environnementale sous forme de normes et d'interdictions est un facteur qui distingue les éco-innovateurs des non-éco-innovateurs. Cependant, les instruments de type taxes environnementales ne permettent pas de discriminer les deux groupes de start-ups. En outre, la présence d'une démarche de responsabilité sociale des entreprises est un facteur de différenciation important.

Les résultats de la typologie des start-ups éco-innovantes mettent en exergue une diversité de profils d'éco-innovateurs. En effet, les entrepreneurs peuvent être regroupés en cinq principaux profils : les entrepreneurs seniors ayant des préoccupations environnementales, les entrepreneurs par nécessité sans préoccupations environnementales, les entrepreneurs à forte conscience écologique, les

entrepreneurs opportunistes axés sur le marché et n'ayant pas de préoccupations environnementales, et les opportunistes « leaders ».

Ces résultats nous permettent de formuler les implications de politique publique suivantes :

- Les résultats de l'AD indiquent que la politique publique ne doit pas uniquement se concentrer sur des instruments réglementaires mais doit également s'appuyer sur d'autres domaines d'application et notamment l'éducation. On voit d'ores et déjà émerger des initiatives pour former aux métiers de demain. Nous pouvons citer le cas des universités « campus transition » ou des « écoles de la transition écologique ». Ces initiatives sont en émergence et leur nombre reste très faible, il est donc nécessaire de renforcer et de soutenir ces initiatives. L'un des objectifs du plan d'investissement dans les compétences⁵¹ (2018-2022) est de favoriser la qualification de la main-d'œuvre pour répondre aux besoins de compétences nécessaires en lien avec la transition écologique. Par contre, nous considérons que cette action reste marginale et devrait prendre une plus grande ampleur.

- L'analyse taxonomique a montré que les éco-innovateurs n'ont pas un profil homogène. La principale implication de la diversité de profils d'éco-innovateurs est que l'élaboration de la politique publique doit prendre en compte cette diversité. Nous avons pu souligner que deux catégories de start-ups (les entrepreneurs seniors ayant des préoccupations environnementales et les opportunistes « leaders ») contribuent fortement au développement de l'éco-innovation radicale et/ou frontstage et affichent une forte orientation environnementale. Ces catégories disposent généralement des conditions nécessaires pour l'aboutissement de leur projet, notamment la disponibilité des ressources financières et l'accès à la connaissance externe (à travers la coopération). Cependant face à l'urgence des problématiques environnementales, il va falloir s'appuyer sur tous les profils pour éco-innover. De ce fait, la politique publique doit être adaptée dans la mesure du possible à chaque profil d'éco-innovateur:

- Nous avons souligné que les entrepreneurs seniors ayant des préoccupations environnementales créent leur entreprise avec des associés. Nous pouvons penser que cela favorise une complémentarité entre l'expérience et la disponibilité des moyens des seniors avec les compétences techniques des jeunes dans les nouvelles technologies⁵² (Isele and Rogoff, 2014; Schott et al., 2017). Lorsque cette configuration n'apparaît pas spontanément, des efforts de mise en relation de ces deux parties pourraient être envisagés. De fait, il semblerait opportun d'encourager le co-entrepreneuriat intergénérationnel notamment par la mise en place d'associations et de structures d'accompagnement privés et public qui pourront mettre en lien

⁵¹ Ce plan peut être consulté sur ce lien <https://travail-emploi.gouv.fr/le-ministere-en-action/pic/>

⁵² Afin de mettre en évidence cette relation de complémentarité, il faudrait orienter une enquête dans ce sens pour obtenir les informations nécessaires. Il serait donc intéressant d'analyser cette relation dans le cadre des recherches futures.

ces deux parties ou en créant des plateformes de mises en relation. Cela pourrait permettre d'améliorer le fonctionnement des entreprises et donc du marché du travail tout en réduisant l'impact environnemental.

- Les entrepreneurs à forte conscience écologique sont des start-ups qui peuvent jouer un rôle important dans le développement durable. Il est nécessaire de les soutenir via des financements et le développement de leur réseau. Les éco-investisseurs partagent les mêmes valeurs environnementales que ces entrepreneurs. Nous considérons que c'est un mode de financement adapté pour ces start-ups en raison des valeurs communes. Pour que les éco-investisseurs et ces start-ups puissent se retrouver sur le marché, il est nécessaire que le réseau soit développé et organisé de façon formelle et que les start-ups et les investisseurs manifestent un signal clair de leur caractère « soutenable » (Demirel et al., 2019). En raison de cette asymétrie de l'information, il est nécessaire de faciliter le rapprochement entre les éco-investisseurs et les entrepreneurs à forte conscience écologique en développant un indicateur reconnu par l'Etat pour évaluer les projets « soutenables ». De plus, il est nécessaire de développer et promouvoir des plateformes d'investissement « vert ».

L'objectif du **chapitre 3**, intitulé localisation des entreprises éco-innovantes : quel rôle pour la diffusion de connaissances ?, est d'étudier le rôle que peuvent jouer les caractéristiques des connaissances technologiques locales à l'échelle des départements français sur la création de nouvelles entreprises éco-innovantes. Nous avons calculé un ensemble d'indicateurs de la base de connaissances technologiques (parenté technologique « *knowledge relatedness* » et variété technologique « *knowledge variety* ») spécifiques qui permettent de comprendre la recombinaison des technologies qui constituent les innovations environnementales en France pour la période 2003-2013. En utilisant un ensemble de données riches et originales basées sur des micro-données au niveau des entreprises et des informations sur les brevets, les principaux résultats montrent que l'interaction entre les technologies environnementales et non environnementales et le soutien des autorités publiques en matière d'environnement sont les principaux facteurs expliquant la localisation des entreprises éco-innovantes. De plus, en appliquant des méthodes d'économétrie spatiale, nous avons constaté qu'il existe une dépendance spatiale dans la création des entreprises éco-innovantes, nous déduisons donc que l'impact de la diffusion de connaissances est principalement local. Ces résultats ont d'importantes implications en termes de préconisations de politique publique. Ces résultats suggèrent en effet qu'il est nécessaire de tenir compte des interdépendances spécifiques des technologies environnementales avec d'autres technologies dans lesquelles le département a une certaine tradition. Par exemple, les départements spécialisés dans l'industrie automobile auraient un avantage comparatif dans le développement de la voiture électrique par rapport aux départements où l'industrie automobile n'est pas développée.

Pour conclure, nous abordons les limites de notre travail et les recherches futures envisageables à partir des résultats de cette thèse.

- Notre recherche s'est concentrée sur les déterminants de l'éco-innovation dans le cas français, son extension à d'autres pays, notamment à travers l'accès à la base de données financière ORBIS, aiderait à fournir des conclusions plus générales et pourrait conduire à une compréhension plus large des déterminants de l'éco-innovation. Cela pourrait contribuer à une meilleure adaptation des politiques publiques aux caractéristiques des différents pays.

- Nous avons analysé la performance des entreprises à l'aide d'une seule mesure (la productivité mesurée par la valeur ajoutée). En plus de cette mesure, les recherches futures pourraient étendre l'analyse en utilisant d'autres mesures notamment la croissance de la production, de l'emploi, de la productivité, de l'intensité des exportations et de l'intensité énergétique.

- Dans le chapitre 1, afin d'étudier l'impact de l'éco-innovation sur la productivité, nous avons utilisé une seule année de retard sur la variable brevets environnementaux. Cependant, l'effet de l'investissement en éco-innovation est généralement observé à moyen ou long terme. De ce fait, la disponibilité de séries chronologiques plus longues permettrait d'étendre cette recherche.

- Dans le chapitre 3, les données des facteurs régionaux qui influencent la localisation des entreprises éco-innovantes sont agrégées à l'échelle du département. Ceci peut constituer un niveau d'agrégation élevé, il en résulte une perte d'information. Une des extensions intéressantes serait de géolocaliser les entreprises afin d'étudier l'agglomération des entreprises éco-innovantes à une échelle intra-métropolitaine.

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Essais sur les déterminants de l'éco-innovation : Une application aux entreprises françaises

Résumé

L'objectif principal de cette thèse est l'étude des facteurs qui influencent le développement des éco-innovations par les entreprises françaises. Nous avons abordé cette question dans différents contextes en utilisant des données originales. Nous contribuons à la littérature empirique en nous intéressant aux aspects entrepreneurial et spatial. Les principaux résultats montrent que les instruments de la politique environnementale impactent différemment les types d'éco-innovations (les technologies de traitement des déchets, les technologies d'énergie renouvelable et les technologies d'atténuation du changement climatique) et que les éco-innovations ne sont pas toujours rentables pour les entreprises. D'où la nécessité d'adapter les instruments de politique publique de sorte à améliorer la rentabilité des éco-innovations. Après la réalisation d'une enquête auprès des start-ups françaises, les résultats de l'analyse ont montré qu'il existe une diversité de profils d'éco-innovateurs. En effet, les start-ups se regroupent en cinq principaux profils qui correspondent à différents déterminants de l'éco-innovation. Nous avons montré empiriquement que les différentes catégories d'éco-innovateurs n'ont pas les mêmes difficultés d'accès aux fonds. Ce qui nous a amené à conclure que les politiques publiques doivent être conçues en tenant compte de la spécificité de chaque profil. Nous avons également montré que la recombinaison des technologies environnementales et non environnementales et le soutien des autorités publiques aux initiatives environnementales sont les principaux facteurs qui expliquent la localisation des entreprises éco-innovantes. De plus, en appliquant l'économétrie spatiale, nous avons constaté qu'il existe une dépendance spatiale claire vis-à-vis de leur création alors que l'impact de la diffusion des connaissances est plutôt local.

Mots clés : Eco-innovation, recombinaison de l'innovation, profils des start-ups, productivité

Abstract

The main objective of this thesis is to study the factors that trigger the development of eco-innovations for the case of French firms. We have addressed this question in different contexts using original data. We contribute to the empirical literature by focusing on entrepreneurial and spatial aspects. The main results show that environmental policy instruments have a different impact on the types of eco-innovations (waste treatment, renewable energy and climate change mitigation technologies) and that eco-innovations are not always profitable for firms. Hence, it is essential to adjust public policy instruments in a way to improve the profitability of eco-innovations. After carrying out a survey on French start-ups, the results of the analysis have shown that there is a diversity of profiles of eco-innovators. Indeed, firms cluster into five main profiles and exhibit different eco-innovation drivers. We have shown empirically that the different categories of eco-innovators do not have the same difficulties in accessing funds. This led us to conclude that public policies must be designed taking into account the specificity of each profile. We have also shown that the recombination of environmental and non environmental technologies and environmental political support are the main factors explaining the location of eco-innovative firms. Moreover, by applying spatial econometrics we found that there is a clear spatial dependence on their creation while the impact of knowledge spillovers is quite local.

Keywords: Eco-innovation, recombinant innovation, start-ups' profiles, productivity